UNIVERSITY OF LEEDS

Faculty of Engineering
School of Computing

PhD Studentship: Fusion of Sensor Data with Buried Asset Records

Applications are invited for an ESPRC funded studentship, to be based in the RAE 5-rated School of Computing to work on a new EPSRC funded project entitled *Mapping the underworld: multi-sensor device creation, assessment, protocols*. This is a joint project with the Universities of Birmingham, Bath and Southampton. Its aim is the creation of a multisensor device to detect buried utility assets. Leeds is responsible for the work package on *Fusion of Sensor Data with Buried Asset Records* in which the sensor data will be intelligently fused with the expectations generated from integrated utility records being created in a complementary project.

Informal enquiries to Professor Tony Cohn, +44 (0)113 343 5482, email a.g.cohn@leeds.ac.uk

The studentship is available from December 1, or another date by mutual arrangement, for a period of 3.5 years.

PhD studentships will be paid at the standard EPSRC rate, plus Home/EU fees. Overseas candidates may apply, but they will need to fund the difference between Home/EU fees and overseas fees out of their own resources.

For details on how to apply please visit www.comp.leeds.ac.uk/mtu/vacancies.htm
Closing date 19 November 2008
Interviews are likely to be between 16 and 23 December 2008

Research Studentship: Fusion of Sensor Data with Buried Asset Records

Further Particulars

Background

The problems associated with inaccurate location of buried pipes and cables are serious and are rapidly worsening due to increasing traffic congestion in major urban areas. These problems were highlighted at the first academe-industry workshop of the Engineering Programme Network (EPN) in Trenchless Technology (NETTWORK) and subsequently at a series of stakeholders' meetings. Following industry lobbying and acknowledgement of the research need by the government, EPSRC chose this topic for its first IDEAS Factory and made five 'Mapping the Underworld' awards totalling £1 million: 4 research grants (location techniques, mapping, data integration and asset tagging) and a new EPN (see http://www.mappingtheunderworld.ac.uk). The IDEAS Factory identified the need for a multi-sensor tool for location of the buried infrastructure and funded a multi-university, multi-disciplinary project "to assess the feasibility of a range of potential techniques that can be deployed in a combined manner to determine the location of, identify and ideally assess the condition of buried assets without breaking the surface". The feasibility study, comprising the first 12-18 months of research on six complementary approaches, is complete and has yielded a clear understanding of the research programme necessary to solve the problem. A new project has been funded, Mapping the underworld: multi-sensor device creation, assessment, protocols which aims to create a novel multi-sensor device that combines complementary technologies for simultaneous surface and in-pipe deployment, to intelligently fuse the outputs to create cross-sections through the ground showing the probability of service locations, to prove the concept of creating 'national geophysical maps' to optimise survey performance anywhere in the UK, to produce a step-change in performance of the included technologies by intelligent selection of operational parameters based on ground properties (derived interactively and simultaneously from field application of the technologies, from simple in-situ tests where relevant and from the national maps), to conduct a programme of rigorous proof tests to define absolute capabilities, and to design a national test facility to facilitate implementation.

Generic Aims and Objectives The overall aim of this project is to create and proof test a multi-sensor 'location device' that can be deployed simultaneously from the surface and from within an existing utility conduit, along with optimised operational protocols based on national geophysical suitability maps. The specific objectives are to:

- Combine four geophysical technologies (ground penetrating radar, acoustics, and active and passive low frequency electromagnetics) to create an integrated, multi-sensor device for simultaneous surface and in-pipe deployment.
- Optimise the outputs from these different types of sensor technology by their combination, using data fusion techniques, to create cross-sections through the ground showing the probability of utility services existing at any specific position, thereby creating a matrix of operational capability.

- Further research the capabilities of ground penetrating radar, acoustic and active and passive low frequency electromagnetic technologies specifically for deployment in the linked surface / in-pipe device, to define their operational limits when combined and deployed in a ‘noisy’ urban street environment, and determine their optimal operational capabilities.
- Produce a UK geophysical soil characteristic map for ‘Mapping the Underworld’ technologies.
- Further enhance the fundamental understanding of signal propagation through and reflection from the underground media encountered in the above operations (i.e. bound and unbound pavement structures, soils, pipes, cables and the materials that they carry) with the specific purpose of ‘tuning’ the techniques to the ground and to the targets (by intelligent choice of operational parameters). This will combine initial readings from the sensors to define ground properties with data from sources such as maps, records and simple in-situ tests.
- Combine the geophysical characteristic map and technology operational capability matrix to facilitate selection of the most appropriate MTU technologies, and the device’s operational parameters, for all locations in the UK.
- Conduct a staged programme of rigorous performance tests, initially in cooperation with, and on sites provided by, the project partners and subsequently at a new bespoke test site in Germany (the Frankfurt Test Facility), for the development and subsequent proof testing of a fully-operational prototype system.
- Investigate how knowledge of what utilities are expected to be underground, obtained from utility statutory records, and integrated using technology being developed in the DTI(BERR)-VISTA project, can help guide interpretation and fusion of the signal data.

The aims and objectives are to be met by eight complementary work packages.

- WP1. Creation of Multi-Sensor Device, Deployment Strategies and Signal Processing (Led by the University of Bath).
- **WP2. Intelligent Data Fusion from the Multi-Sensor Device and Statutory Records (Led by the University of Leeds)**
- WP3. Ground Penetrating Radar Advancement to support Multi-Sensor Device (Led by the University of Bath).
- WP4. Acoustic Technologies Advancement to support Multi-Sensor Device (Led by the University of Southampton).
- WP5. Low Frequency Electromagnetic Field Technologies to support Multi-Sensor Device (Led by the University of Birmingham).
- WP6. Magnetic Field Technologies to support Multi-Sensor Device (Led by the University of Southampton).
- WP7. Intelligent Tuning of the Device to the Ground and Targets (Led by the University of Birmingham).
- WP8. Proving Trials and Specification of National MTU Test Facility (Led by the University of Birmingham).

You will be primarily involved in, and responsible for, jointly with Professor Cohn and a research fellow to be appointed, for work package 2. A description of WP2 follows:

Work Package 2 (WP2). Fusion of Sensor Data with Buried Asset Records
Advances made in MTU Phase I. Leeds' role in MTU Phase I was to build an integrated representation of utility records, to facilitate their use and interpretation, and maximize their value. Leeds obtained a further £630k of DTI funding (the VISTA project) to expand this activity, in collaboration with 20+ industrial partners, including many utility companies who are collaborating actively and enthusiastically, contributing a further £630k of in-kind contributions. See www.comp.leeds.ac.uk/mtu and www.vistadtiproject.org. We have identified several test areas across the UK for which we are developing integrated maps, and comparing these with surveys conducted by the VISTA (and MTU Phase II) partner Adien Ltd. Progress has been made in the integration of buried asset records at both the logical and physical levels through the development of an integrated data model and thesaurus/ontology for partner records, allowing a dynamic integration of their records in a unified, common spatially referenced form. The integrated database not only contains the recorded positions assets in a common spatial reference system, but also a rich variety of attribute information for records, such as size, material, age, and sometimes depth information. It may also indicate the confidence in the accuracy of the records. The global schema we have developed means that this information can be accessed easily, without knowing the proprietary details of the way each individual utility has stored and recorded their data. Queries can be made transparently through the common virtual integration interface provided. VISTA further aims to deliver a prototype decision support tool built on integrated statutory records, with in-street recordings of surface features (e.g. street furniture) including visualization appropriate to the user and the degree of uncertainty. Further information can be found at www.comp.leeds.ac.uk/mtu. These two projects provide the necessary foundation for the extension of the decision support tool to fuse sensor data with the integrated statutory record database, OS data and other survey information. In WP2 we will thus focus on combining data from a range of sensors with buried asset data, with the goal of maximizing the confidence in the presence and location of buried assets.

Aim To fuse geo-referenced information from multiple sensors and to combine this with an integrated database of buried asset records to increase confidence in their presence and location, and to determine missing asset records.

Methodology A key aspect to the WP is the need to perform spatially indexed data fusion. An overview of WP2 is presented in Figure 1 (left). Two sources of data are available: geo-referenced sensor data, and integrated utility records from the VISTA project. We intend to explore two techniques to compute a maximally confident representation of the presence, location, and depth of underground assets at a survey site. The two routes to alignment of sensor and VISTA data are indicated as 'A' and 'B' in the diagram. Method 'A' converts the symbolic representation from the utility records into simulated sensor responses, and computes a Kohonen map (see below) for both this and the simulated data. A spatial correspondence between the two is then computed in order to integrate the two sources of information. This will match based not only on geo-position, but also on the commonality of the Kohonen map (real and simulated) for each geo-position which implicitly take account of attributes such as material, size and depth. Method 'B' converts data from each sensor individually to a geo-indexed symbolic representation that is then compared with the utility records directly, drawing on techniques used by the PI and others in earlier vision interpretation work. We will evaluate both methods, and also whether it is advantageous to combine the predictions from both techniques to provide an overall prediction with increased confidence (see the bottom right box in the figure) – in both strands, probabilities are attached to all representations so as to be able to compute confidence measures for the final interpretation.

A methodology for handling uncertainty from each of the sensor data streams (and from the statutory record database) is central to this WP. Four different detection techniques are being investigated (in WPs 3-6); whilst some of these are independent in that they will only detect certain kinds of material or only in certain kinds of ground conditions, in some situations an asset may be detectable by multiple sensor types and this can provide reinforced confidence in the location of the asset. Confidence may also be increased through the integration of the symbolic statutory data which may provide confirming (or otherwise) evidence for sensor values.

In strand A: the first task is to develop a common spatial framework for the sensor data. We seek a clear representation of the sensor data which can represent detection events as unambiguously as possible, by combining different data sources, whilst preserving any remaining uncertainties. Data at the geo-spatial level can be represented via a simple grid for each sensor element, and differences in resolution can be resolved via interpolation. In strand A we plan to investigate sensor fusion at the spatial level using a Kohonen mapping component. This is a well-established technique for summarizing and visualizing multidimensional data, but which has not been applied to spatially indexed sensor fusion because of the lack of a suitable strategy for handling spatially arranged data with a range of discrete responses to different materials. Recent work has placed the Kohonen approach in a probabilistic framework, which allows the representation to be learned via the EM algorithm. The technique is illustrated in Figure 1 (right). The approach fits a 2D deformable mesh through a high-dimensional dataset such that the topology is preserved. The data can then be plotted via the mesh in 2D. Dense data regions attract more nodes in the mesh and are thus given greater emphasis (area) in the 2D representation. Each region in this abstract space will correspond to a particular asset type and size and/or condition and/or soil type and/or depth.

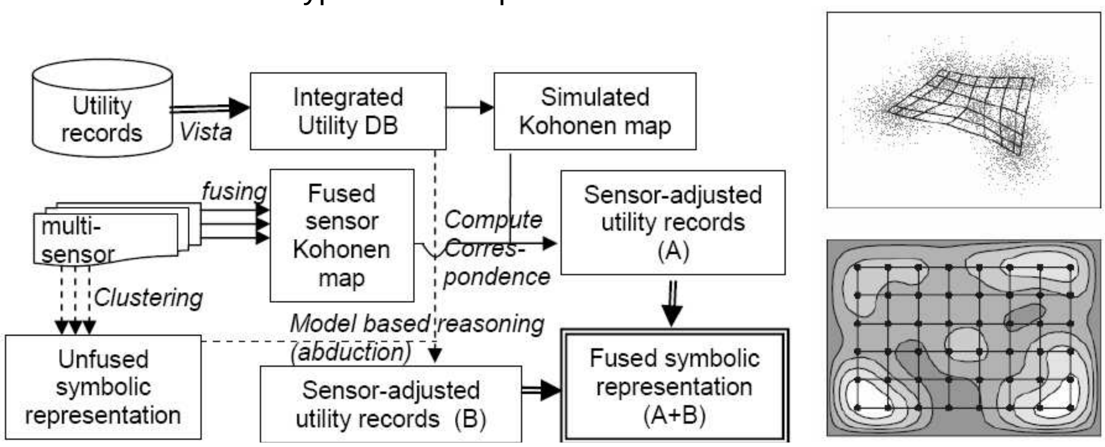

Figure 1. Left: Relations between tasks in WP2; single line arrows indicate strand A, dashed arrows, strand B, double lines indicate processes common to A&B or their combination. Right: A Kohonen map of a disparate database.

Since spatial discrepancies between symbolic records and sensor data may be difficult to resolve at the spatial level, an alternative is to integrate the two data sources at the symbolic level which we will investigate in strand B. Here, the data from each sensor is first converted to symbolic form; model based reasoning, using the knowledge from the integrated utility database (positional, size and materials) will then be used to fuse these symbolic components to a single spatially integrated form. A crucial part of the methodology here is to exploit the idea of sensor interpretation as an abductive process: every sensor input must be explained by some aspect of the final interpretation, combined with the background knowledge (principally the utility database and the associated ontology, and a model of the signal profiles of the various asset types).

Some sensor data may represent noise, or unmapped buried objects, and either of these are a valid explanations, though a preferred abduction (explanation) will be to interpret as much sensor data not as noise, consistent with the expectations provided by the integrated utility database. The proposed research will seek to explore both strands A and B, along with ways of synthesizing the approaches to gain the benefits from both (illustrated in the bottom right box of Fig. 1. It is expected that The RF will principally explore one of the strands, and the student the other, though they will collaborate on both aspects.

Another aspect to WP2 is to explore the extent to which the models which enable the interpretation of the sensor data (i.e. the recognition of particular asset types) and the generation of the signal profiles, can be learned, using supervised learning techniques. The training data will come from sensor surveys for fully mapped sites. We expect to be able to build initial models by hand which will enable a first version of the prototype, but learning should facilitate the acquisition of much more robust and fine grained models. Another approach we may consider is to explore the analogy with SLAM (simultaneous location and mapping) techniques[9] which enable a mobile robot to simultaneously (usually using probabilistic particle filters) build a map and localize itself with respect to the partially built map. The analogy with the present problem is that the VISTA records provide the partial map (since they are unreliable and uncertain), and the sensor readings provide the localization corresponding to the sensor readings of an actual mobile robot. This is useful since SLAM techniques allow multiple localizations to be considered in parallel, and the most probable one selected according to the current set of sensor readings.

The work plan is divided into the two strands, A and B, but also into several phases. In phase 1, before sensor data is available from the other university partners, we will design and build the overall architecture, and test it using data acquired from the industrial partner Adien, a VISTA project partner, who will supply sensor data (GPR and electro-magnetic resonance) from their archive of surveys (their business is to provide expert services in locating and mapping buried utilities). Once we have built the ability to produce simulated sensor data from the VISTA database, then we can also use this to develop and test the continuous sensor fusion techniques. In phase 2, we will then extend the system to the new sensor types to be included in the multi-sensor device being developed in the WPs 1,and 3-6 and will be able to evaluate the system on real data acquired from these sources.

Deliverables The deliverables of this work package are:

- Techniques to resolve differences in resolution, positioning and depth sensitivity for the four sensor types and the available buried asset records to arrive at a common data representation for sensor fusion at the spatial and symbolic levels.
- Techniques to learn a model for the correspondence between a symbolic record of an underground asset (taking account of attributes such as material and size) and expected sensor readings, and creation of such models.
- Techniques to compute spatial correspondences between interpreted sensor readings and utility records.
- Techniques to determine whether a set of sensor readings correspond to an unrecorded asset or object, and dually whether a recorded asset is undetected by sensor readings.

- Software implementations of the above, along with interfaces to the VISTA Decision Aid system (for which visualization software is also being developed to facilitate the display of underground asset information of varying complexity and certainty).

The School of Computing

The School of Computing at the University of Leeds, which recently celebrated its 50th anniversary, has strong traditions in both research and teaching. It was awarded grade 5 in the 2001 Research Assessment Exercise. The School has some 70 teaching, research and support staff, teaches around 500 full-time equivalent students at undergraduate and postgraduate levels, and is nationally and internationally active across a wide range of research programmes. Our objectives are:

· To undertake world class research across a range of areas.
· To provide a high quality learning environment at all levels of higher education, that is internationally recognised and professionally relevant.
· To provide an environment that encourages all staff to achieve their full potential and enjoy maximum job satisfaction.

The current Head of the School is Professor Roger Boyle. Professors Ken Brodlie, Tony Cohn, Peter Dew, Martin Dyer, David Hogg, Peter Jimack and Jie Xu are the other members of the professoriate. Teaching is undertaken at the School level, with research and professional development of staff taking place in academic groups or smaller, more focused and constantly evolving research groups. See http://www.comp.leeds.ac.uk for further general information about the School.

Research

The School's research environment is prospering and continuing to grow. Our leading multidisciplinary activities complement underlying research in foundational aspects of computing. We receive funding from all UK research councils and have close contacts with end-users of computer and information systems through many collaborative programmes with partners elsewhere in the University and in other national and international institutions. Within the University, we have strong ongoing research collaborations with other Schools in the Faculty of Engineering, and with the faculties of Mathematical and Physical Sciences, and Biological Sciences, all of which were awarded Grade 5 or higher in the latest RAE exercise. Our research programme is focused in three areas:

- Artificial Intelligence: Computer Vision, Natural Language Processing, and Knowledge Representation and Reasoning.
- Multidisciplinary Informatics: Biosystems, Grid Computing, Scheduling, Scientific Computation, and Visualization and Virtual Reality.
- Theory of Computing: Algorithms and Complexity, and Program Analysis and Logic Programming.

(Further details of the activities of all these research groups can be found online - http://www.comp.leeds.ac.uk/research). Members of the School participate actively in a number of interdisciplinary research institutes and centres within the University, for example:

· Centre for Computer Analysis of Language and Speech.
· Centre of Computational Geography.
· Centre for Computational Fluid Dynamics.
· Centre of Medical Imaging Research.
· Centre for Virtual Working Systems.
· University Interdisciplinary Institute in Earth, Energy and the Environment.
· Institute for Transport Studies.
· Keyworth Institute for Manufacturing and Information Systems Engineering.

Teaching

The School has a large and active teaching programme and currently offers three single Honours degrees, as well as a range of joint Honours and multidisciplinary undergraduate programmes. In all of these, the School places considerable emphasis on delivering a high quality learning and teaching environment. Leeds graduates carry a high reputation for the quality of their education and university experience, whether they progress into higher degrees or commercial, industrial or research-based careers. Degree programmes offer opportunities for students to engage with research or application based work as they prefer: engagement with the School's research groups and industry (local and national) is offered. The optional undergraduate placement ("sandwich") programme is successful and popular.

Infrastructure

The School is housed in extensive, contiguous modern accommodation central to the campus. Academic staff are provided with high quality office and other facilities suited to the needs of research and teaching. Up to date computer and networking provision is ubiquitous and of very high reliability. School research staff and students work alongside a range of laboratories.

The university provides facilities of the highest quality: extensive libraries and computer provision are within easy reach. Support services for staff (e.g. Staff Development, Human Resources) are all available. Opportunities for personal development are many and are widely used by most staff. All staff can expect support (in particular some financial support for junior staff) from the School during their career with the university.

Social and recreational facilities are available on a scale that matches the size and diversity of the institution, including a brand new swimming and sports centre under construction. Additionally, the city of Leeds has acquired a deserved reputation as a cultural, commercial and social hub of the north of England, with internationally respected theatre, opera, sporting and other activities within easy reach. A large conurbation, Leeds is very compact and access to national parks via private or public transport is straightforward.

See http://www.comp.leeds.ac.uk for further general information about the School.

The University of Leeds

The University of Leeds is acclaimed world-wide for the quality of its research and teaching. One of the largest universities in the UK, Leeds is also highly popular among students applying for taught courses. Its size and international reputation enable the University to offer one of the widest ranges of academic courses in the UK. It has around

30,000 students are attached to some 700 different first-degree programmes and 300 postgraduate degree programmes.

Leeds is among the top ten universities for research in the UK and is internationally acknowledged as a centre of excellence in a wide range of academic and professional disciplines (including top rated departments in the pure and applied sciences, medicine and engineering). Its broad research and skills base and superb facilities attract interest from major multinationals and small local businesses alike. Many of its research initiatives cross traditional subject boundaries and Leeds currently promotes projects through 58 inter-disciplinary centres and seven research schools. An emphasis on innovative research and investment in high-quality facilities and first-rate infrastructure means that no fewer than 35 departments are rated internationally or nationally 'excellent'.

The University is a member of the White Rose University Consortium, a strategic partnership between Yorkshire's leading research universities of Leeds, Sheffield and York. The combined research power of the three institutions ranks alongside that of the Universities of Oxford and Cambridge and accounts for 86% of the region's research spend.

Duties and Responsibilities

The requirements of the PhD Studentship position are:

- To undertake research, in collaboration with other members of the project team, commensurate with the aims and objectives of the EPSRC project Mapping the underworld: multi-sensor device creation, assessment, protocols.
- To publish outcomes from the project in appropriate high quality conferences and journals, and to present the research at such conferences.
- To attend and contribute to regular project meetings at Leeds and at the other partner sites in the UK.
- To help liaise with the other academic and industrial project partners, and to help prepare period project reports.
- To liaise with the Research Fellow to be appointed to the project.
- To play a wider role in the academic activities of the Knowledge Representation and Reasoning research group as appropriate.

You will be responsible to and supervised by the project investigator at Leeds: Prof Tony Cohn.

Person Specification

The person appointed to the studentship will be required to have:

- A Bachelors at grade 2.1 or better (or the equivalent) or Masters degree in a relevant subject or equivalent experience.
- Knowledge and experience of current research in areas relevant to the project as outlined above in the description of WP2.
- Excellent computer programming skills.

- Good communication skills, including written. (Candidates with English as a foreign language must fulfil the requirements specified here: www.engineering.leeds.ac.uk/comp/pg/PGRapply.shtml)
- The potential to write up research findings for academic publication.
- Ability to collaborate successfully with co-investigators and project partners.
- Willingness to undertake further learning and personal development appropriate to the position.

How to apply

The Application for Research Degree study form can be downloaded from the Research Degrees and Scholarships Office and must be sent to that office. Apart from this clearly completed application form, we will need the following supporting documents to process your application:

- a curriculum vitae (resumé)
- a short description of which areas of the project interest you and how your previous knowledge and experience equip you to undertake this research.
- complete transcripts/certificates of your academic results
- two signed and sealed letters of references, at least one of which should be from an academic referee (or these can be (e)mailed to us directly by your referees.

Guidance for your referees is available via this letter (RTF or PDF)

The application form should be completed online or emailed to the Research Degrees and Scholarships Office. All other documentation should be sent to the School of Computing's postgraduate admissions tutor at rsadmit@comp.leeds.ac.uk.

Informal advice can be obtained from Prof. Tony Cohn, a.g.cohn@leeds.ac.uk +44 113 343 5482.

The studentship is available from December 1, or another date by mutual arrangement, for a period of 3.5 years.

PhD studentships will be paid at the standard EPSRC rate, plus Home/EU fees. Overseas candidates may apply, but they will need to fund the difference between Home/EU fees and overseas fees out of their own resources.

Replies will be treated in complete confidence.

If you are selected for interview you can expect to hear from the University **not later than 4 weeks** after the closing date. If you are not selected for interview the University will not contact you again.

Further advice including information for international students and for disabled or dyslexic students can be found here:
http://www.leeds.ac.uk/rds/prospective_students/apply/I_want_to_apply.html

Data Protection

The information you provide in your application will be used to consider your suitability for the post for which you have applied. If your application is not successful the information will be disposed of confidentially after 9 months. If your application is successful and you are appointed, your information and future data will be processed in accordance with the University's Data Protection Code of Practice. A copy of this code can be obtained from either the University's Human Resources Department or by visiting:

http://www.leeds.ac.uk/hr/policy/index.htm

Health and Safety Responsibilities

You are required to adhere to and comply with the provisions of the Health and Safety at Work Act, related Regulations, and act in accordance with the University's Policy on Health and Safety which can be accessed via:
http://www.leeds.ac.uk/safety

In addition you are also required to co-operate with regard to the implementation of the Health and Safety arrangements and should not interfere with or misuse anything provided in the interest of Health, Safety and Welfare at Work.

To find out what it's like to work at the University of Leeds, view our DVD online at: http://www.leeds.ac.uk/hr/jobs/dvd.htm

Equality and Diversity Statement

The University of Leeds is proud to be a multi-cultural community. We value diversity, and are determined to ensure:

- that we treat all individuals fairly, with dignity and respect;
- that the opportunities we provide are open to all;
- that we provide a safe, supportive and welcoming environment – for staff, for students and for visitors.

We recognise that we still have work to do to secure a truly inclusive community, and we are committed to a wide-ranging plan of action to tackle discrimination and to promote diversity.

The Equality and Diversity Statement forms part of the University's Equality and Diversity Policy, which applies to staff and students alike and is available on the University's website at: http://www.equality.leeds.ac.uk/ed/policy/

The University has published the following policy and code of practice which are linked to the Equality and Diversity policy. They are also available on the University's website:

- The Race Equality Policy,
- The Code of Practice on Harassment and Bullying

Further policies are being developed, and will be made available on the University's website in due course.

Further information and advice are available from The Equality Service, Telephone: +44 (0)113 343 3927 or by email to equality@leeds.ac.uk.