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LINKS TO THE INTErSECT FARADAY PARTNERSHIP – 3rd Annual Report

FROM THE SOFTWARE SUPPORT FOR METROLOGY PROGRAMME

BY

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1. INTRODUCTION

This document is the third annual report on the links between the INTErSECT (Intelligent sensors for control technologies) Faraday Partnership and the Software Support for Metrology NMSPU programme. The report is produced under project 6.4 of the SS*f*M programme.

In section two, we provide a history of the INTErSECT scheme. We then present an outline of the work carried out in the three relevant INTErSECT flagship projects, and it's relevance to SS*f*M both throughout the final year of the first programme and to future programmes.

As well as being the last year of the first SS*f*M, 2001 was scheduled to include the completion of the flagship projects launched under INTErSECT. This still appears to be the case for most of the projects, despite difficulties recruiting and retaining researchers. However, none of them has finished in time to be comprehensively reported on in this project.

Just as SS*f*M is continuing past its original formulation, so is the INTErSECT scheme. We include a section on the future of the latter scheme, and point out its relevance to the continuing SS*f*M programme.

2. OVERVIEW OF INTERSECT

INTErSECT is a partnership between a group of academic and industrial parties, set up under the UK's Faraday Initiative. The Faraday Initiative has established four programmes to develop university based research, postgraduate training and other technology transfer activities to support key industry needs, particularly those from which smaller and medium sized enterprises can benefit.

The four Faraday Partnerships were announced in 1997 by EPSRC, who are making available £1 million in research grants to each partnership. INTErSECT, managed by NPL and Sira, chose a competitive scheme, whereby academic institutions associated with INTErSECT produced proposals of research, and industrial companies became sponsors of the scheme.

The academic institutions were encouraged to develop their proposals in close alliance with the industrial sponsors, so that the research would be likely to find an enthusiastic audience once completed. They were similarly encouraged to incorporate SMEs within their proposal, either those known to industrial sponsors, or to the academic institutions, or from a group of SMEs known to be enthusiastic about the INTErSECT scheme.

The industrial composition of the INTErSECT partnership is currently as follows:

- BNFL
- Corus
- GlaxoSmithKline (Glaxo Wellcome & SmithKline Beecham joined as separate companies pre-merger)
- HSE
- ICI
- Kidde International
- London Underground
- Rolls-Royce
- Unilever
- Syngenta (formerly Zeneca Agrochemicals)

The initial call for proposals concentrated on three major technical areas (INTErSECT themes) in which the sponsoring industries had a strong interest.

- New sensors, for example, using novel optical techniques; for spectroscopic applications, gas sensing, automatic inspection and corrosion measurement. Other techniques may be applied to long standing measurement and control needs in the light of new component and information technologies.
- Non-invasive measurement, analysis and modelling of external and internal structural characteristics, of all sorts, particularly for non-rigid materials.
- Data fusion, data management and complex system design, including validation of data integrity.

Four projects were launched from these three themes. The first theme is not particularly relevant to the SS*f*M programme, and the one project from this theme is not tracked by the liaison activities carried out under SS*f*M. The other three projects, although not solely concentrating on metrological problems, have lessons both to learn from and inform to the mathematical-metrological community.

3. THE FLAGSHIP PROJECTS

In this section, we describe the four projects that have been selected by the panels of industrialists to receive an allocation of INTErSECT funding, and their success is of primary importance to the reputation of INTErSECT. The backgrounds to each project are the same as in previous years, but are included here for completeness.

3.1 The application of data fusion to the multi-sensored intelligent engine

3.1.1 Background

This project was jointly proposed by Warwick and Manchester universities, and addresses two of the INTErSECT themes (data fusion and novel sensors) corresponding to the different backgrounds of these two academic institutions. Many of the industrial sponsors of INTErSECT are involved in this project, in particular Rolls-Royce, British Steel, and DERA. Along with them are a number of SMEs who will be in a position to bring the products of the research (both software implementations and sensor hardware) to market. Rover were also a prominent industrial partner, strongly involved in the formulation of the project, but left the INTErSECT scheme during the year, thus making necessary some redirection of the project.

The underlying idea of the project is to strike the right compromise between physical measurement and data processing. In a hostile environment, or one where intrusive measurements are not encouraged, the engineer is less able to access data that would enable him to estimate the true state of the system, or values derived from the state, such as performance or efficiency measures. Many types of engine are just such environments: internal combustion or turbine engines, and steel blast-furnaces will typically operate at high temperatures and pressures, will often be isolated by their casing, and will have moving parts that must not be obstructed by sensors. In order, then, to measure the performance of an engine, it is necessary to have as few (and as robust) sensors as possible making direct measurements, and to augment this with as many indirect measurements as are at the engineers' disposal in an intelligent manner.

The Warwick-Manchester plan is for the former partner to develop new sensors suitable for such environments, and the latter to investigate in tandem the best way in which to make use of the data from these new sensors, together with the incorporation of currently feasible measurement processes. Thus, not only should the development of the new sensors allow a better calculation to be made, but also the careful examination of available data processing capabilities (namely data fusion) should inform the sensor developers about what type of measurements would be desirable to provide a complete description of the system.

3.1.2 Progress and relevance to SS*f*M

This project produced, in its first year, a technical guide to the variety of mathematical techniques relevant to data fusion. This was restricted to the project partners. It was felt by the industrial sponsors that a more easily approachable guide to the subject would be of benefit to the partners and to industry in general. With this aim, it was decided to edit the guide to become an extensible, web-based document covering the techniques included in the early paper-based version, but including introductions and examples that would make the techniques accessible to a wider audience. This guide will shortly be published at www.datafusion.org.uk. It is clear that our ability to deliver this guide has been contingent on the team's experience in data fusion through SS*f*M and other routes, and that the direct industrial customer for this work will make the final document more oriented to club-members' activities than if it had been developed in a pure research environment.

Outside this generic task, work has progressed on various industrial case studies, the work being carried out mainly by Manchester University research staff, and the results of the work are restricted within the partnership. However, we can report that the work in processing tomography data, and the promotions and use of techniques such as principal components analysis has been influenced by other work carried out within SS*f*M.

Generally, the number of new techniques the SS*f*M team has been introduced to through this specific project is small, but the benefit has been through gaining assurance that some of the techniques and skills already developed are directly applicable to industrial problems.

3.2 Intelligent data analysis and fusion techniques in pharmaceuticals, bioprocessing and process control

3.2.1 Background

This project, submitted under the academic leadership of University College London (UCL), addresses the single INTErSECT theme of "data fusion, data processing, and complex system design". As can be seen from the title of the project, it is mainly directed towards the requirements of the chemicals sector of the INTErSECT sponsors, and as such may appear not to have a direct link to SS*f*M, outside the latter's concern with the VAM programme. However, it is shown below that there are links that should be maintained, due both to the technical content of the project and the potentially fruitful links with non-traditional industries.

The structure of the project is that the industrial sponsors each have a PhD student working on their problem, and those students are jointly supervised by Sira and UCL. There is then a post-doctoral researcher who brings together the research, with the help of other project members (including NPL).

The individual sub-projects are quite different, one trying to learn lessons from very sparse amounts of data, building up rules using bayesian networks. Another sub-project is targeted towards novelty detection amongst vast amounts of data. The approaches taken have the common factor that they use modern "intelligent" techniques of data and information processing (such as genetic algorithms, and support vector machines), rather than the metrologically-traditional techniques of numerical regression and optimisation.

3.2.2 Progress and relevance to SS*f*M

This project has made substantial progress in the variety of pharmacalogical problems it has tackled. The UCL team had a dedicated researcher for each of the industrial problems, each of whom develops intelligent data analysis tools to suit the individual requirements of the partners.

Above this was a further researcher who endeavoured to unite the research. Thus there was research in complementary fields of, for instance: (i) finding a classifier that could mimic humans in selecting from a small number of items each with a relatively large number of features; and (ii) finding a classifier that could efficiently analyse data that was so copious that traditional automated approaches wouldn't scale. The project was made cohesive by the overall target of examining ways of combining classifiers so that optimal performance might be achieved.

Although classification is distinct from the usual disciplines of mathematics that are relevant to metrology (typically estimation/regression and optimisation), the techniques developed in this project were of relevance to metrological applications. Support Vector Machines, for instance, are a technology that was introduced to several members of the SS*f*M team through involvement with this project, and there are adaptions of this technique to cope with data-driven regression. Also, classification (of faults, modes of behaviour,…) plays a large role in data fusion, where the extraction of this knowledge will inform further data processing; and as we shall see in 3.2 the classification process often precedes the estimation process in new measurement problems, and the techniques encountered through this project are expected to reap a benefit there. Also, this project will feed into the data fusion guide (to be published at www.datafusion.org.uk), giving examples of the feature and decision fusion techniques that have been developed during the project.

3.3 Acoustic Emmission Traceable Sensing and Signature Diagnostics

3.3.1 Background

This project was submitted by Brunel University, and was accepted under the "non-invasive measurement" INTErSECT theme.

Most physical processes give off acoustic emissions (AE), much of which is inaudible to the human ear. Sensors can be tuned and used to detect such signals and algorithms and software developed to identify signatures in the signal and interpret these to provide information on the physical process which generated the signals.

The Brunel project has identified a number of "demonstrator" projects within the industrial sponsors involved in the project. These cover a wide part of the domain of problems tackled by acoustic emission analysis, such as tool-wear monitoring, process monitoring, and condition monitoring.

The aspect that is most relevant to the SS*f*M programme is the data analysis surrounding all these demonstrator projects. To this end, the author is the joint supervisor (along with a Brunel team-member) of a PhD student at Brunel who is responsible for the data-processing and analysis for all the demonstrator projects. This is leading to a sizeable knowledge-base in the application of various signal-processing and feature extraction methods; one of the more valuable lessons to be learnt, however, is the absolute necessity of careful pre-processing of AE, as there are often alignment problems, and spurious data are not infrequent.

One of the major problems of AE analysis is the separation of physically significant emissions from the general background noise. The traceability between an AE event and a physical cause is somewhat tenuous, and a main purpose of the work is to strengthen this.

3.3.2 Progress and relevance to SS*f*M

The student involved in this project is only now entering the third year of his PhD, and so the work is obviously not as near completion as in the two projects above. However, some good progress has been made in both the selection of features from acoustic emission signals, and the classification of signals according to these features.

Software has now been developed that allows a flexibility in the choice of features that are extracted, ranging from simple temporal features, such as duration, through some spectral estimation procedures (giving position and strength of spectral lines) to sophisticated spectro-temporal wavelet features. Some of these have direct physical meaning, and obviously this is the ideal for maximal traceability; but others may simply fit the data, yet offer no immediate physical interpretation. The latter will entail further investigation if AE analysis is to be used seriously in metrology. We have given feedback to materials-scientists at NPL on some of the features that are proving useful, and have received physical motivation for some of these already – and it is interesting to note that even slightly esoteric features such as wavelets have a physical "reasonableness" once they are described to the scientist.

The classification of AE events according to features initially proceeded by visual examination. When it became evident that a small number of features would not suffice (as had been expected all along), it was necessary to move onto more automated methods. Support Vector Machines have proved useful in this, as they can easily break high dimensional space into distinct areas based on some training data – and once again we hope to obtain results empirically, then consult with the physicist to gain some understanding of the empirical results.

3.4 Development of Fibre Optic luminescent thermometry

The NPL interaction with this project is specifically in the development of sensors, rather than dealing mathematically with any measurements, and as such lies outside any obvious connection with SS*f*M. Hence we simply provide a summary description for completeness.

This flagship project is aimed at research into the feasibility of the use of fluorescence thermometry in a project to undertake novel research to address the underpinning temperature measurement needs of the industrial partners, Corus group (British Steel), Kidde International and BFNL, in close association with NPL and two SMEs, Queensgate Instruments and EM Technology and carried out through City University, London. The research has the prime objectives of developing sensor technology for high temperature measurement (200-700°C), for example for non-destructive monitoring of refractories, alarm system applications and measuring high temperatures in hostile environments, such as commercial combustion monitoring and the nuclear industry. In addition a further aim is to is to develop and evaluate these sensor concepts for very high temperatures (>1,000°C), for use in kilns and in chemically hazardous environments and in high radiation fields.

4. THE FUTURE

4.1 The continuation of flagship projects

The three flagship projects in which SS*f*M team members are involved continue for up to one year. The interaction continues to be supported by Strategic Research money from NPL. It is predicted that there is still an amount of research of interest to the SS*f*M-2 programme to come out of the flagship projects; thus there may be opportunities for the "Links with Universities" project of SS*f*M-2 to take advantage of this research, amongst the other activities of this project.

The work in the Manchester/Warwick and UCL projects that might be of interest to the SS*f*M club community will be summarised in the data fusion guide mentioned previously, and the imminent publication of this has already been indicated to the club, and beyond, through an article in the Spring 2001 edition of Counting on IT – the SS*f*M newsletter. The signal processing aspect of the Brunel project has relevance to the emprical modelling and the "new directions" projects. There remains the possibility that research from this project be presented at a future club meeting.

4.2 The continuation of INTErSECT funding mechanisms

The INTErSECT scheme continues in two guises. The first, a simple extension of previous incarnation, is to support a number of flagship projects through EPSRC funding. Once again EPSRC has earmarked up £1.5M, this time with the themes being:

- Sensors
- Measurement
- Instrumentation,

and 8 full proposals have been received by INTErSECT in response to the Announcement of Opportunity (AO). As can be seen, there is a less explicit link with the work of the SS*f*M programme. Although the instrumentation theme does make reference to data fusion and extracting information from data, the response to the AO makes it clear that the industrial sponsors believe that, for the time being, the emphasis of the first set of projects on data processing (with three of the four flagship proposals having a large element of SS*f*M-related activity) has perhaps satisfied their requirement in this area. The proposals, at the time of writing, are being reviewed by EPSRC – only two currently have direct NPL involvement, and the emphasis on the physics of measurement has meant that none have any members of the SS*f*M team on board.

The second form of continuation for INTErSECT is the new funding possibly available from the NMS. This, according to an early announcement of opportunity, will have a similar structure to the EPSRC work, but with several key changes of emphasis. Firstly, the NMS-funded projects may also address an additional theme of Non-destructive Testing and Evaluation.

Obviously, being sponsored by the NMS, there will be a stronger focus on metrology, and the announcement states "Work to be carried out should address research and development relating to the adoption by industry of traceable measurement, new measurement processes, measurement standards, and regulation-related measurements. The emergence of new instrumentation products and measurement services as a result is to be encouraged." Another notable feature is that "The work proposed should not already be part of the planned NMS programme." Clearly the EPSRC projects would not be looked upon favourably if they duplicated work carried out under the NMS or any other scheme, but this condition ensures that any interface between INTErSECT and SS*f*M must be thought through carefully from now on.

At the time of writing, proposals have yet to be submitted, so the author is not in a position to announce the details of how SS*f*M may link in with the NMS part of INTErSECT.

4.3 The future links between SSfM and INTErSECT

The second SS*f*M programme contains no specific link to the INTErSECT scheme. However, there is a project looking at the wider remit of links with universities. The contacts made through involvement with three flagship projects (covering four universities) will not be left to dwindle, but will be fed into this larger network of academic contacts and resources that can be called upon by SS*f*M.

5. CONCLUSIONS

This report has outlined the existing structure of the INTErSECT initiative, listed the academic and industrial partners, described the various liaison activities, and described the Flagship projects in which they are involved.

Through involvement with INTErSECT, the relevant SS*f*M team members have become acquanted with techniques that have enhanced their ability to model and analyse a wide range of data, some with a strong metrological flavour, others quite outside the normal type of data handled at a national measurement institute. The contact with academic institutions has kept us up to date with new techniques that are being developed, and reassured us that we are sufficiently skilled to put them into practice. Conversely, the close contact with specific industrial problems, mainly with a strong measurement element, has ensured that relevance of our work has been maintained and enhanced.

In general, the industrial sponsors of the INTErSECT scheme have benefitted from having the academic research and manpower at their disposal, and have used it to make progress in solving difficult problems involving the analysis and use of measurement data. The academic partners have responded well to the real problems, and have been delighted to see that long-term research has been produced that has a real use.

The INTErSECT scheme is entering a new phase, and there is less of a focus on the data processing side, and more of an emphasis on the physical side of sensors and measurement. This roughly coincides with the ending of a specific "Links to INTErSECT" project within SS*f*M, and a move to a more general project on links with universities. It is intended that the contacts made through the expiring project will be transferred to the new programme, that the broader scheme will maintain the benefit of exposure to the latest techniques, and that the SS*f*M team will continue to apply these techniques to real life problems in measurement science.