Engineering and
Computational Science
for Oncology Network

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ECSON REPORT

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ECSON - The facts

Engineering and Computational Science for Oncology Network (ECSON) is a research project funded by the UK Engineering and Physical Sciences Research Council (grant No. EP/F013698/1) under "Collaboration for Success through People" call. The project is hosted by the Applied Digital Signal and Image Processing Research Centre (ADSIP) based within the School of Computing, Engineering and Physical Sciences at the University of Central Lancashire, with co-investigators from Radiotherapy Developing Technologies (DTRT), North Western Medical Physics at The Christie Hospital, and the General Engineering Research Institute (GERI) at Liverpool John Moores University.

Acknowledgement

We are grateful for the participation of the partners mentioned in this report and the contributions made by them to the success of this project. For this report, ADSIP led the design and editorial work of the report as well as compilation of the Introduction and Project Outcomes sections; DTRT led the compilation of all the clinical science sections, in particular the Project Workshop section; and GERI led the compilation of the Building the Network section.

Dr. Bogdan Matuszewski (Principal Investigator)

Prof. Christopher Moore (Clinical Science Lead)

Prof. David Burton (Instrumentation Lead)

Prof. Lik-Kwan Shark (Image Processing Lead)

Funded by

EPSRC
Engineering and Physical Sciences Research Council

ECSON Report Contents

Introduction to ECSON Project

The Engineering and Computational Sciences for Oncology Network (ECSON) (**www.ecson.org**) is a networking project, which started on 1st of October 2007. The project is funded by the EPSRC (EP/F013698/1) under its "Collaborating for Success Through People" programme with a budget of £189,512 and the EPSRC supporting it for 18 months with a contribution of £154,386. The project is co-ordinated by the Applied Digital Signal and Image Processing Research Centre (ADSIP) at the University of Central Lancashire (UCLan), with co-investigators from Developing Technologies Radiotherapy (DTRT) of North-Western Medical Physics at the Christie NHS Foundation Trust, and the General Engineering Research Institute (GERI) at the Liverpool John Moores University (JMU). Initially the project started with 8 additional partners from 4 European countries, but over the course of the project so far ECSON has engaged with 24 institutions from 6 European countries.

ECSON Genesis

The ECSON project was conceived by ADSIP, DTRT and GERI to support, complement, utilise, and extend the scientific results and research activities of another project called Metrology Guided Radiation Therapy (MEGURATH) (**www.megurath.org**) also funded by the EPSRC (EP/D077540/1; EP/D077702/1; and EP/D078415/1). Radiation therapy cures cancer by precisely targeting a tumour with small doses of radiation, which are delivered repeatedly over many days. Advanced computerised pre-treatment planning helps to minimise any risk to healthy tissues, often with the help of a CT scan. However, when it comes to the treatment itself, when radiation is actually being directed at the tumour, the options for monitoring the patient's position and any changes to the patient internal anatomy are still very limited. This is where the MEGURATH project came into play with its objectives to digitally image and measure what is happening to the patients during their radiation therapy and in this way maximise the benefits of complex new radiotherapy plans in order to both improve cure rates and reduce side effects. The ECSON project was proposed as a platform for human-based activities in the realm of the MEGURATH project.

ECSON objectives

The general aim of the ECSON project is to create an effective research focus around radiation therapy with the network functioning as a UK and European hub to co-ordinate an effective, regulated flow of knowledge, people and data between, academic and clinical institutions, and to liaise with interested equipment suppliers. To achieve this aim, all the proposed network activities are organised around five strategic objectives, namely, supporting, complementing, utilising and extending the research, translational and clinical activities stated in the MEGURATH project as well as providing research training opportunities. These objectives are described as follows:

Objective of supporting: There exist a number of different scientific approaches to similar problems in radiation therapy. Opportunities are to be created through the proposed network activities to gain knowledge of the existing different methodologies, to exchange test data and results, and to undertake comparative performance evaluation.

Objective of complementing: In recognition of the complementary and high calibre research work carried out by the organisations participating in the network, and their different clinical focuses, this objective concentrates on transfer of their respective scientific knowledge and distinctive expertise throughout the network.

Objective of extending: The science and technologies emerging from the MEGURATH project with the potential for new clinical applications is to be exploited in the network by investigating its effectiveness on different modalities of data and considering different anatomical sites.

Objective of utilising: The ECSON forms a formidable European network with all the essential ingredients to make use of the metrology guided philosophy and technology in other medical treatments and to attract further partners. The network provides an excellent breeding ground for cross-fertilisation of ideas, and to enable the consortium to lead the development of an engineering and computational science road-map for oncology for UK and Europe.

Objective of research training: The network provides unique opportunities to allow a number of bright researchers to work at different organisations for a short period of time thereby enabling them to gain additional, multidisciplinary research experience in a different culture and environment, and training them to become future leaders of research in this field. Opportunities are also provided for other research students of the consortium to benefit from the visiting experts via the invited seminar/lecture series.

ECSON activities

To support the project objectives a number of activities were undertaken, including:

- a series of seminars delivered at collaborating institutions by the core project partners and network members
- short one day workshops aimed at identifying exact areas of common interest and complementary scientific knowledge, involving exchange of ideas, helping to define precise objectives for the long-term collaboration and to lay down the foundation for the multilateral workshop
- longer term visits, investigative in nature, focused on cross-fertilization of ideas, performance evaluation and development of new applications leading to joint publications and collaborative project proposals
- a multilateral project workshop to solidify the network and to identify clinical and scientific questions for the future.

Building the Network

Visit at the Holycross Cancer Centre, from left to right: Mr Artur Ostrowski (Simens Medical Solutions), Prof. Tomasz Zieliński (AGH), Dr Bogdan Matuszewski (UCLan), Mr Andrzej Skalski (AGH), Dr Thomas Marchant (Christie), Dr Gareth Price (Christie), Prof. Lik-Kwan Shark (UCLan), Prof. Christopher Moore (Christie), Dr Paweł Kukułowicz (Holycross), Dr Gerald Krell (OVGU), Dr Jian Kun Shen (UCLan).

The first stage of the ECSON project involved selecting a cadre of potential team members, drawn from all across Europe.

These institutions were chosen from two principal sources:

- Firstly, those institutions with which the ECSON core partners (UCLan, Christie and JMU) had previous contact, and possibly prior collaboration experience with,
- Secondly, institutions which although the core partners may not have worked with previously, they were known to have experience and a profile which might be of relevance to the objectives of ECSON.

Original ECSON collaborators

The collaborators identified by the ECSON core partners consisted of:

Laboratory/Institution	Principal	Country	Expertise Profile
LIRIS - Laboratoire d'InfoRmatique en Image et Systèmes d'information, CNRS/INSA de Lyon/Université Claude Bernard Lyon 1	Prof Behzad Shariat	France	Image Processing, 3D Modelling.
Department of Radiotherapy, Universität Otto von Guericke Magdeberg	Prof Günter Gademann	Germany	Clinical Radiation Oncology
Department of Scientific Information, Institute of Public Health, Collegium Medicum. Jagiellonian University	Dr Mariusz Duplaga	Poland	Medical Informatics; Pulmonary medicine.
Department of Telecommunications, AGH University of Science and Technology, Krakow	Prof Tomasz Zieliński	Poland	Signal and Image Processing including compression and spectral analysis
Signals and Images Laboratory, Istituto di Scienza e Tecnologie dell'Informazione "Alessandro Faedo" Area della Ricerca CNR di Pisa	Prof Ovido Salvetti	Italy	Artificial Intelligence, image understanding, diagnostic imaging
Institut für Elektronik, Signalverarbeitung und Kommunikationstechnik (IESK) Universität Otto von Guericke Magdeberg	Dr Gerald Krell	Germany	Signal and Image Processing
Equipes Traitement de l'Information et Systèmes (ETIS), l'Ecole Nationale de l'Electronique et de ses Applications, l'Université de Cergy-Pontoise	Prof Sylvie Philipp-Foliguet	France	3D Shape Indexing and Analysis
French National Institute for Research in Computer Science and Control, Sophia Antipolis, (INRIA)	Dr Gregoire Malandain	France	Medical Image Processing
3dMD	Julian Bott	UK	3D sensing

Visit at the AGH University of Science and Technology, from left to right: Prof. Tomasz Zieliński, Dr Paweł Turcza, Mr Mirosław Socha, Mr Andrzej Skalski, Dr Bogdan Matuszewski, and Prof. Christopher Moore.

ECSON short workshops

Having selected this group of ECSON collaborators to join the core partners, the next stage was to arrange a series of bilateral visits (workshops) in which the ECSON core partners visited each of these research centres, sometimes accompanied by other ECSON collaborators, in order to fully explore areas of expertise in detail and to investigate possible avenues of collaboration. The schedule for these visits is given below.

Team Member Visited	ECSON Core Partners in Attendance	Other ECSON Team Members Present	Date of Visit
Holycross Cancer Center, Kielce	UCLan and Christie	Dr Gerald Krell	19 Feb 2008
Department of Computer Science, AGH University of Science and Technology, Krakow	UCLan, Christie and JMU	Dr Gerald Krell	20-21 Feb 2008
Department of Scientific Information, Institute of Public Health, Collegium Medicum. Jagiellonian University	UCLan, Christie and JMU	Dr Gerald Krell	20 Feb 2008
LIRIS - Laboratoire d'InfoRmatique en Image et Systèmes d'information, CNRS/INSA de Lyon / Université Claude Bernard Lyon 1	UCLan, Christie and JMU	Dr Gerald Krell Prof Günter Gademann Dr Gregoire Malandain Dr Aymeric Histace	13-14 Mar 2008
Equipes Traitement de l'Information et Systèmes (ETIS), l'Ecole Nationale de l'Electronique et de ses Applications, l'Université de Cergy-Pontoise	UCLan, Christie and JMU	Dr Gerald Krell Prof Günter Gademann Prof Behzad Shariat Prof Frank Dubois	10 Sep 2008
Signals and Images Laboratory, Istituto di Scienza e Tecnologie dell'Informazione "Alessandro Faedo" Area della Ricerca CNR di Pisa	UCLan and Christie	Dr Gerald Krell Prof Günter Gademann Prof Behzad Shariat Prof Tomasz Zieliński Dr Mariusz Duplaga Dr Michael Beuve	31 Oct 2008
Institut für Elektronik, Signalverarbeitung und Kommunikationstechnik (IESK) Universität Otto von Guericke Magdeberg	UCLan, Christie and JMU	Prof Behzad Shariat	17 Mar 2009
Department of Radiotherapy, Universität Otto von Guericke Magdeberg	UCLan, Christie and JMU	Prof Behzad Shariat	17 Mar 2009

These meetings had a number of objectives;

- To cement a firm relationship between the core ECSON partners (UCLan, Christie and JMU) and the invited project collaborators.
- To enable the core partners to gain an in depth understanding of the expertise, capability and equipment provision available to each of the collaborators.
- To provide the collaborators with an understanding of the objectives of the ECSON project and its likely successors and to provide the collaborators with a contextual background to the project in terms of the European projects INFOCUS and ARROW and specifically the EPSRC project Megurath.
- To foster links between collaborators who had complementary interests.
- To lay the foundation of mutual understanding which would be necessary if the multi-lateral workshop, planned to take place towards the end of ECSON, was to be a success.

It can be seen that at none of these meetings were all of the collaborators present simultaneously. This was intentional. At this stage only the core partners had a complete overview of the total expertise and experience of the group. The rest were invited to specific meetings, where they would have a particular interest. The holistic view of the entire project would be unveiled to the team when they were all present at the end of project workshop at Mottram Hall.

Although these, largely, bilateral meetings (workshops) obviously differed in detail from one host to another, the agenda followed a common pattern. Firstly, the host would be invited to give a series of presentations detailing their recent projects in areas relevant to ECSON; this would often be accompanied with a laboratory or clinic tour to view facilities.

Next the ECSON core partners would give three presentations reviewing the issues in modern radiation cancer treatment and detailing their work over the last 10 years on developing technological tools designed to aid the accuracy and effectiveness of treatment. The core partners would present their work performed within the EPSRC Project Megurath and would also explain the objectives of ECSON. The agenda would then finish with what was perhaps the most important element of the meeting, a series of "round table" discussions on how the work we had seen from the host institution could be built upon in the context of research to develop new and novel radiation oncology technical support devices.

It should be noted that while the table above lists only the presence of the principal of each team, in reality teams generally brought a delegation of between 2 and 5 colleagues to the meetings and this was strongly encouraged by the core partners. The host institution was encouraged to invite a wide spectrum of colleagues to the meetings – especially including PhD students, as these sessions would offer an excellent experience in high level technical debate which would be very beneficial for students to observe, even if their personal contribution was limited.

The main bilateral meetings were generally kept informal in order to encourage as great a level of technical exchange as possible and to foster an atmosphere of collaboration likely to produce exciting radical new ideas in the field. In the overwhelming majority of cases these sessions were highly successful in achieving all of their objectives and enabled the core partners to undertake the detailed planning of the Mottram Hall workshop, at which all collaborators would be present together for the first time, with confidence that all collaborators would feel able to contribute and would fully understand the context of the problem area, as well as the future objectives.

As the result of the above mentioned visits, the following additional collaborating institutions were invited to the network:

Institution	Principal	Country	Expertise Profile
Microgravity Research Centre. Université Libre de Bruxelles	Prof Frank Dubois	Belgium	Optical Non-Contact Measurement and Image Processing.
Holycross Cancer Centre, Kielce	Dr Paweł Kukułowicz	Poland	Medical Physics
AGH University of Science and Technology, Kraków	Prof. Paweł Gryboś	Poland	Instrumentation and ASIC design
University of Pisa	Prof. Giuliano Manara	Italy	Instrumentation

Contributors to ECSON Meetings

In addition to the investigators a great many scientists, clinicians and engineers contributed to one or more ECSON meetings. A full listing of ECSON contributors is listed below:

Prof. AGH Piotr Augustyniak
AGH University of Science and Technology, Krakow, Poland.

Prof. Fulvio Bessi *Pisa University Hospital, Pisa, Italy.*

Dr. Michael Beuve *University Claude Bernard, Lyon, France.*

Dr F.A. Bezombes *Liverpool John Moores University, Liverpool, UK.*

Prof. D.R. Burton *Liverpool John Moores University, Liverpool, UK.*

Dr Sara Colantonio *ISTI-CNR, Pisa, Italy.*

Prof Frank Dubois *Free University of Brussells, Brussells, Belgium.*

Dr Mariusz Duplaga *Jagiellonian University, Krakow, Poland.*

Dr Rafał Frączek
AGH University of Science and Technology, Krakow, Poland.

Prof. Günther Gademann
Otto von Guericke University Hospital, Magdeburg, Germany.

Dr Aymeric Histace
University of Cergy-Pontoise, Cergy-Pontoise, France.

Dr Gerald Krell
Otto von Guericke University, Magdeburg, Germany.

Dr Pawel Kukułowicz *Holycross Cancer Centre, Kielce, Poland.*

Dr Jian Kun Shen *University of Central Lancashire, Preston, UK.*

Prof. Lik-Kwan Shark
University of Central Lancashire, Preston, UK.

Prof. Michael Lalor *Liverpool John Moores University, Liverpool, UK.*

Dr. Francis Lilley *Liverpool John Moores University, Liverpool, UK.*

Prof. Giuliano Manara *University of Pisa, Pisa, Italy.*

Dr Gregoire Malandain
French Nat. Instit. for Res in Comp Sci & Control, France.

Dr Thomas Marchant *Christie Hospital, Manchester, UK.*

Dr Bogdan Matuszewski
University of Central Lancashire, Preston, UK.

Dr Christian Merkwirth *Jagiellonian University, Krakow, Poland.*

Prof. Agostino Monorchio *University of Pisa, Pisa, Italy.*

Prof. Christopher Moore *Christie Hospital, Manchester, UK.*

Prof Jean-Michel Moreau *University Claude Bernard, Lyon, France.*

Dr Davide Moroni *ISTI-CNR, Pisa, Italy.*

Prof. Paolo Nepa *University of Pisa, Pisa, Italy.*

Prof. Maciej Ogorzałek *Jagiellonian University, Krakow, Poland.*

Dr Piotr Oramus *Jagiellonian University, Krakow, Poland.*

Mr Artur Ostrowski *Simens Medical Solutions, Poland.*

Prof Sylvie Philipe-Foliguet
University of Cergy-Pontoise, Cergy-Pontoise, France.

Dr Gabriele Pieri *ISTI-CNR, Pisa, Italy.*

Dr Frédéric Precioso
University of Cergy-Pontoise, Cergy-Pontoise, France.

Dr Gareth Price *Christie Hospital, Manchester, UK.*

Prof. Ovidio Salvetti *ISTI-CNR, Pisa, Italy.*

Prof. Mario Salvetti *University of Pisa, Pisa, Italy.*

Prof. Behzad Shariat *University Claude Bernard, Lyon, France.*

Mr Andrzej Skalski
AGH University of Science and Technology, Krakow, Poland.

Mr Mirosław Socha
AGH University of Science and Technology, Krakow, Poland.

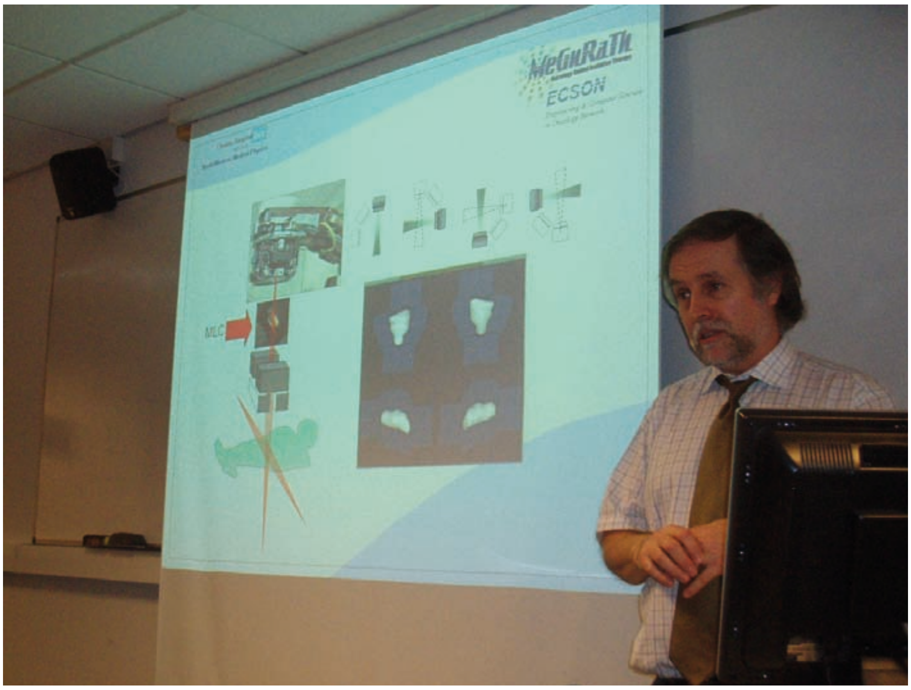
Dr Grzegorz Surówka *Jagiellonian University, Krakow, Poland.*

Dr Paweł Turcza
AGH University of Science and Technology, Krakow, Poland.

Dr Gillian Whitfield *Christie Hospital, Manchester, UK.*

Prof. AGH Wojciech Kucewicz
AGH University of Science and Technology, Krakow, Poland.

Prof. Tomasz Zieliński
AGH University of Science and Technology, Krakow, Poland.



Prof Christopher Moore giving seminar on "Combining X-ray and Light for a Dynamic View in Image Guided Radiation Therapy

ECSON Seminars

In order to support the ECSON objectives, throughout the project a number of seminars took place, which were aimed at disseminating the network members' respective scientific expertise, and identifying existing synergies and differences in the research and application areas between different network members. Last but not least, these seminars also provided unique training opportunities for younger researchers. Below is a complete list of the seminars that took place.

Dr Bogdan Matuszewski
Applied Digital Signal and Image Processing (ADSIP) Research Centre, University of Central Lancashire, "*Deformable Models in Medical Image Processing*", 1 September 2007, AHG University of Science and Technology, Kraków, Poland

Prof Tomasz Zieliński[1], and Dr Mariusz Duplaga[2]
[1]Telemedicine Group, Department of Telecommunication AGH University of Science and Technology, Kraków, Poland
[2]Department of Scientific Information, Institute of Public Health, Collegium Medicum, Jagiellonian University, Kraków, Poland "*Image and Video Processing Tasks in Computer Aided Medical Interventions on the Example of Transbronchial Biopsy*", 25 October 2007, UCLan

Prof. Christopher Moore
North Western Medical Physics, The Christie NHS Foundation Trust "*Combining X- rays and Light for a Dynamic View in Image Guided Radiation Therapy*", 23 January 2008, UCLan

Prof. Lik-Kwan Shark and **Dr Bogdan Matuszewski**
Applied Digital Signal and Image Processing (ADSIP) Research Centre, University of Central Lancashire, "*Introduction to ECSON project*", 7 July 2008, Signals and Images Laboratory, Institute of Information Science and Technologies (ISTI), CNR PISA, Italy

Dr Bogdan Matuszewski
Applied Digital Signal and Image Processing (ADSIP) Research Centre, University of Central Lancashire, "*Medical Computer Vision & the ECSON project*", 21 July 2008, Signal and Image Processing Research Laboratory (ETIS), ENSEA, University of Cergy-Pontoise, France

Dr Bogdan Matuszewski
Applied Digital Signal and Image Processing (ADSIP) Research Centre, University of Central Lancashire, "*Notes on Deformable Segmentation, Registration and Tracking*", 11 December 2008, Otto-von-Guericke University, Germany

Dr Gerald Krell
Institute for Electronics Signal Processing and Communications (IESK), Otto von Guericke University, Magdeburg, Germany "*From low level image processing to motion and emotion analysis - selected applications in medicine, biology and industry*" 14 January 2009, UCLan

Dr Davide Moroni
Signals and Images Laboratory, Institute of Information Science and Technologies (ISTI), CNR PISA, Italy "*Image Segmentation, 3D Geometry and Shape Matching*", 14 January 2009, UCLan

Dr Aymeric Histace and **Dr Frédéric Precioso**
Signal and Image Processing Research Laboratory (ETIS), ENSEA, University of Cergy-Pontoise, France "*Active contours: from basic to recent advances in medical imaging*", 27 April 2009, UCLan

It should also be noted that these seminars and bilateral meetings (workshops) were far from being the only contact between the team members and the core partners during this period. A number of other activities were undertaken including; secondment of staff and students, collaborative work, joint publications and joint project submissions. These aspects are detailed later in the project outcomes section.

Project Workshop (Mottram Hall)

Thinking behind the workshop agenda

The ECSON network was founded primarily from established contacts in the academic-scientific and medical physics communities that were engaged in radiotherapy research and development. In order to provide some guidance for discussion on pilot visits to the full range of collaborating institutions, an analysis of key technical radiotherapy projects undertaken at The Christie Hospital in the last decade was undertaken. The results were used to produce themed context briefings and to explicitly indicate some of the challenges facing radiation oncology. Circulating these across the network in advance of the workshop was performed with the aim of ensuring new collaborators would be able to identify opportunities for using their particular expertise.

Three main themes emerged from the analysis: *(1) Generating Information Concurrently with Irradiation; (2) Simulation and Modelling from Limited, Noisy & Dynamic Data;* and *(3) New Technologies and Analytical Methods for Preparation and Follow-Up.* In turn these relate to what is taking place at each instance of therapeutic radiation delivery, adapting a staged treatment to measured circumstances, and more objective forms of patient follow-up once a treatment has been completed. All three themes are at the core of the radiotherapy process, but are still under-developed if not entirely neglected. The breadth of the challenges they pose suggests that wide-spread engagement across the scientific disciplines is necessary to catalyse productive new research and development.

It was recognised from the outset that some collaborators attending the Mottram Hall workshop (**www.ecson.org/workshops**) would have had little or no direct involvement with radiation oncology. Hence, keynote talks would be needed to reinforce each theme prior to any collective discussions. In any diverse gathering, establishing common purpose is essential from the outset. Such was the objective of the opening keynote talks to be delivered by Prof. Gademann and Prof Moore, which would signal the importance of the European dimension to this UK sponsored workshop, and reinforce the fact that the network could only succeed if there was an open cross-disciplinary and cross-professional meeting of minds.

Following pilot visits to ECSON network partner sites, it became clear that ECSON participation would benefit from still wider representation. In particular, the oncology challenges and scientific insight into their complexity could best be defined by experts in the field, namely research active oncologists. Like their medical physics colleagues they are clinician-scientists who are already working across the scientific and professional divides – medicine, physics and biology in particular. However, they are well equipped to steer the attention of academic-scientists towards problems for which solutions could result in clinically worthwhile advances, as well as new knowledge.

Hence, in common with the opening talks, it was decided that two keynote talks would be delivered for each session, specifically describing work being undertaken in the relevant theme. One keynote talk would concentrate on medical aspects and the other on technical background. From these exemplars, the synergy between medical and technical research would then be clear to see for all delegates, whatever their background. Most importantly, the keynote talks would be interactive and fresh in the minds of delegates prior to discussion.

The invitation to the ECSON Workshop requested individuals to rank their level of interest in the three themed sessions, which it should be recalled were designed to facilitate identification of the potential links between oncology challenges and various scientific fields of research. At the same time, space was provided for respondents to briefly indicate the key issues and opportunities they themselves would like to see covered in the workshop. In effect, delegates would have the opportunity to determine an expanded agenda. Doing this well before the workshop convened allowed the ECSON investigators to carefully craft well balanced break-out groups. The groups were intentionally a mixture of clinician-scientists and academic-scientists, guided by group leaders from the ECSON investigator institutions, whose task was to maintain purpose and momentum. Table-1 shows the final composition of these groups for each of the workshop sessions.

On the days of the workshop itself, following the paired keynote talks, delegates would collectively identify and rank the issues to be discussed in their breakout sessions. Following the breakouts, delegates would reconvene to hear and discuss the feedback delivered from 'rapporteurs' elected by each group. This feedback, along with accompanying notes, would be collated and summarised by ECSON's Christie investigators.

Delegate	Research Area	Institution		Session 1	Session 2	Session 3
BREAKOUT GROUP LEADERS						
Moore C	Medical physics	Christie-Manchester	UK	Orange	Green	Red
Burton D	Opto-electronics	GERI-Liverpool	UK	Red	Yellow	Orange
Matuszewski B	Computer vision	UCLan-Preston	UK	Green	Red	Yellow
Shark LK	Image processing	UCLan-Preston	UK	Yellow	Orange	Green
CLINICAL RESEARCHERS						
Faivre-Finn C.	Oncology	Christie-Manchester	UK	Yellow	Yellow	Red
Jackson A	Oncology	Manchester University	UK	Yellow	Yellow	Red
Price P	Oncology	Manchester University	UK	Green	Green	Orange
Whitfield Gi	Oncology	Manchester University	UK	Red	Red	Green
Jena R	Oncology	Addenbrookes-Cambs	UK	Orange	Yellow	Yellow
Gademann G	Oncology	MFUS-Magdeburg	D	Orange	Red	Orange
Alheit H	Oncology	Dresden	D	Red	Orange	Yellow
Jensen A	Oncology (ions)	DKFZ-Heidelburg	D	Yellow	Green	Green
Duplaga M	Diagnostics	Jagiellonian-Krakow	PL	Green	Orange	Red
Kukułowicz P	Medical physics	Hollycross Cancer Centre, Kielce	PL	Yellow	Red	Orange
Balosso J	Oncology (ions)	Grenoble University Hospital	F	Yellow	Red	Red
MacKay R	Medical physics	Christie-Manchester	UK	Yellow	Red	Orange
Marchant T	Medical physics	Christie-Manchester	UK	Green	Yellow	Green
Price G	Medical physics	Christie-Manchester	UK	Red	Orange	Yellow
Parkhurst J	Medical physics	Christie-Manchester	UK	Yellow	Green	Orange
ACADEMIC RESEARCHERS						
Lalor M	Opto-electronics	GERI-Liverpool	UK	Green	Orange	Red
Lilley F	Opto-electronics	GERI-Liverpool	UK	Orange	Red	Green
Murphy M	Cells	GERI-Liverpool	UK	Yellow	Green	Yellow
Gdeisat M.	Opto-electronics	GERI-Liverpool	UK	Green	Yellow	Red
Gross S	Cells	GERI-Liverpool	UK	Green	Yellow	Red
Lisboa P	Statistics	GERI-Liverpool	UK	Green	Yellow	Green
Quan W	Image processing	UCLan-Preston	UK	Orange	Yellow	Green
Zhang Y	Image processing	UCLan-Preston	UK	Red	Green	Red
Mein S	Image processing	UCLan-Preston	UK	Orange	Yellow	Red
Beuve M	Radiobiology	UCBL-Lyon	F	Orange	Orange	Yellow
Moreau JMl	Image processing	UCBL-Lyon	F	Green	Orange	Yellow
Malandain G	Modelling	INRIA-Antipolis	F	Yellow	Green	Red
Histace A	Image processing	Cergy-Pontoise	F	Red	Orange	Orange
Philipp-Foliguet S	Image processing	Cergy-Pontoise	F	Green	Green	Red
Precioso F	Image processing	Cergy-Pontoise	F	Orange	Orange	Orange
Krell G	Signal Processing	OVGU-Magdeburg	D	Green	Red	Orange
Moroni D	Pattern Analysis	ISTI-Pisa	I	Red	Green	Green
Gryboś P	Instrumentation	AGH-Krakow	PL	Red	Red	Orange
Arevalillo-Herraez M.	Optics	University of Valencia	ES	Red	Yellow	Green
Soleimani M	Reconstruction	Bath University	UK	Red	Yellow	Green
Chang J	Graphics	Bournemouth University	UK	Orange	Red	Yellow
Betcke M	Reconstruction	Manchester University	UK	Red	Green	Orange
Snow S	Detectors	Manchester University	UK	Yellow	Red	Green
Haas O	Control systems	Coventry University	UK	Red	Red	Yellow

Table-1 - ECSON Mottram Hall Delegates and Breakout Session Arrangements

Red/Green/Orange/Yellow (right) = Coded session breakout group

Black font (centre) = Collaborator attendees.

Orange font (centre) = Invited attendees

Group photo of the ECSON workshop delegates

Issues and breakout feedback

For each of the three sessions at Mottram Hall in January 2009 this section:

- Reproduces the short session title and briefing issued to all delegates.
- States the titles and authors of the invited keynote talks.
- Summarises the issues and their rank, in order of importance and interest, that were collectively identified by the workshop delegates before discussing them in four breakout groups. The summary includes feedback provided by rapporteurs on reconvening after the breakouts.

SESSION 1

Generating Information concurrently with Irradiation. Right now, we don't do much during patient irradiation. Of course 3D X-ray imaging is capable of revealing soft-tissue structures in the treatment room, but it cannot be used during irradiation, whereas 2D imaging can. Dynamic 3D optical imaging is an emerging technology for body surface positioning and tracking during irradiation, but is literally superficial.

a. How far can we go with these information sources - do we need others?

b. Can we collect information and process it fast enough for on-line, or even real-time, treatment control?

c. Do we feed information back to patients and clinical staff, through personal interactive display, augmented reality?

d. Should we also be doing this during the irradiation phases of planning e.g. PET, CT & simulator scanning?

Key Note Talks

'New Technologies in Radiation Therapy' (Dr Andrew Jackson, Clinical Oncologist, Academic Radiation Oncology Dept, Manchester University, Christie Hospital, Manchester, UK.)

ABSTRACT

New technology would ideally provide radiation oncologists with good anatomical, dosimetric and biological information. At present even the first of these, anatomical imaging, is problematic - simply because of the diversity of modalities and their commercial implementations. This presentation will consider the urgent need to combine imaging modalities and associated supporting data in a manner that is easily interrogated, not just visualised. Radiotherapy now has morphological imaging in the form of pre-treatment fan-beam kilo-voltage (kV) X-ray CT used for planning purposes, in-treatment mega-voltage (MV) X-ray planar images and cone beam CT (MV-CBCT) reconstructions, X-ray kV-CBCT and kV fluoroscopy for positioning. 3D optical imaging is finding its way into the clinic, in-room functional MRI is on the verge of being commercially available and PET is on the horizon. A range of issues is still to be resolved: the levels of X ray exposure; the fact that imaging is available before, after but not during therapeutic irradiation; there is no truly 4D or intra-fraction imaging; soft tissue detail often remains inadequate for accurate tumour delineation let alone automated segmentation; in-room CBCT Hounsfield numbers are not accurate enough for dosimetric planning purposes; the tracking of tissue sub-volumes is not yet practical, which obstructs dosimetric modelling that could guide adaptive treatment on the basis of predicted biological effect. More adventurous parameters still cannot be easily established - variation in tumour sensitivity, hypoxia and tumour response being amongst the most important. New technology is being adopted rapidly but it is raising as many questions as it answers.

Plenary session from left to right: Dr Gillian Whitfield, Dr Andrew Jackson, Dr Michael Beuve, Dr Paweł Kukułowicz, and Prof. Christopher Moore

'A Measured Approach'
(Dr Tom Marchant, North West Medical Physics, Christie Hospital, Manchester, UK)

ABSTRACT

This talk introduces some of the problems addressed in the EPSRC MEGURATH project, in particular that of unknown daily patient variations in body surface and target throughout treatment, i.e. during irradiation; and the limitations of current modalities used for image guided radiotherapy (IGRT). One such modality, cone beam CT (CBCT), suffers from non-optimal image quality and does not presently provide real-time data. Image quality is vital both for visualisation of target structures and accurate re-calculation of delivered dose distribution. Possibilities for CBCT image quality improvement are discussed, including reconstruction methods and post processing of images, both with potential for incorporation of strong prior knowledge as is often available in radiotherapy. The possibilities for extraction of real-time motion data from CBCT projection sequences are also explored. Current methods are limited to tracking of implanted markers. Markerless tracking of target structures in kV projection images is currently challenging, but may be possible with the aid of dynamic anatomical models. Finally, optical surface sensing technologies are introduced, with particular emphasis on complementarity with CBCT. Temporally synchronised optical surface and kV CBCT acquisition has been demonstrated in MEGURATH. In combination with surface texture feature tracking, this raises the possibility of motion correction of CBCT reconstruction, based on optical data without using markers.

Discussion and Breakout

i. Delegate Identified Issues

1. Correspondence
1. Tissue Characteristics

2 Bio-impact and changes.

3. Markers

4. Image quality
4. Physical and anatomical impact/changes

(~ ranked in order of interest)

ii. Feedback from Breakout groups

Overview

'Correspondence'

- Discussion included the emerging use of optical sensors for patient surface measurement during irradiation, absolute spatial tissue tracking and deformation relative to the treatment plan. The optical measurement of skin texture to track skin element motion and the possibility of relating this to sub-surface tissues was also considered. The use of skin texture as an aid to patient setup was discussed. A UK National Institute for Health Research project was reportedly underway to exploit this possibility in a form of augmented reality. Commercial stereo tracking was thought to be too inaccurate for this purpose. The use of infra-red, which is known to improve the visibility of vasculature texture, was suggested.
- Establishing correspondence at depth in tissues, using added solid or liquid contrast, naturally overlapped the direct discussion of marker technology. The need to develop refined correspondence between planned and delivered treatments was questioned, with some delegates feeling that rigid body transformation between the two was clinically sufficient. It was suggested that radiotherapy outcomes might not be as sensitive to displacements as some think given patient dynamics. Others thought that establishing volume correspondence between images captured at fractions throughout treatment itself might move radiobiological modelling forward, and make it easier to improve our knowledge of the real effectiveness of increasing the complexity of treatments.

Breakout group discussion

- It was noted that there was little in-vivo information about the biomechanical properties of tissues, which made it difficult to relate external skin movements to tissues at depth. A complicating factor was the nature of internal anatomical motion, heart, lung, bowel etc., which need not be correlated with body surface changes. It was noted that exit beam dosimetry might reflect such changes.
- So far as cone beam CT image reconstruction was concerned it was suggested that motion correction to improve reconstructed image quality could have significant value in matching to treatment planning data. The possibility existed that motion was more important than shape change in radiotherapy. Motion impacted the planning target volume significantly.
- Shape changes, like shrinkage, are problematic. Should treatment fields be shrunk correspondingly, particularly when it isn't known if there is any remnant disease left behind? Similarly, growth and acute tissue reactions such as swelling were problematic. Furthermore, natural landmarks that could be tracked might not be stable.

'*Tissue Characteristics*'

- The use of endoscopy in radiotherapy, comparable to brochoscopy, was considered. It was suggested that fluorescence or infra-red vascular imaging might be used to identify the spread/regression of cancerous lesions that are almost impossible to see with X-ray and MR techniques. The use of ultrasound was considered as a way of providing tissue biomechanical data for deformation modelling.

'Bio-impact and changes'

- Measurement during radiotherapy treatment delivery was seen to be an important and much neglected topic for at least half of the break-out groups, particularly those with strong clinician-scientist representation. The discussion centred on a possible move to invasive introduction of active sensors in the patient. These would be variously used to measure: the delivered dose in-vivo at depth, impedance changes that are related to blood flow, development of fibrotic tissues and biochemical changes in situ via fluids analysis, e.g. cytokines, glucose, oxygen, amino acid levels.
- An underlying thought was that, instead of measuring in-vivo dose etc., it might be more useful to measure response. This would significantly move the focus of research towards the measurement of biochemical and biophysical parameters. It was noted that radiologists already perform procedures such as that devised by Seldinger for catheter based sampling. The question was posed – "Why not adopt existing radiological practices in radiotherapy?". It was suggested that both passive and active payloads could be delivered at appropriate sites by minimally invasive methods during treatment itself. Even Raman spectroscopy might be potentially useful.
- The ethical issues were debated robustly when the break-out delegates reconvened: invasive procedures would need to provide actual benefits to balance any associated risks.

'Markers'

- These were seen as necessary simply because image quality in radiotherapy was often very poor. It was also noted that, in addition to solid X-ray 'fidicuals' in the form of surgically implanted small metallic rods, there were liquid markers or 'contrast injections/swallows'. Some of these have already been imported from radiology with the emergence of X-ray image guidance in the radiotherapy treatment room. However, it was noted that invasive marking lacked precision and did cause local perturbation such as swelling, blood pooling (haematoma) and other changes such as fibrosis. Nevertheless, shaped markers and patterned placement was noted to be emerging as a way of gaining additional spatial information such as orientation.
- Active internal-tracking/marker possibilities were identified, including autonomous 'smart-pills or bullets' for use in hollow tracks. These are already under development in some centres for carry anything from miniature cameras to active payloads. The lack of control for positioning and retrieval, and to some extent size, was seen as limiting their use.
- There was interest in the suggested use of 'smart dust' and electromagnetic markers during radiotherapy. It was noted that the relatively large commercial EM device 'Calypso' was finding some clinical use, and that Bandala had recently reported small 'MEMS' for remote internal organ tracking with 6 degrees of freedom for radiotherapy. Externally induced, internal tissue marking, such as the grid-magnetisation used to study cardiac dynamics, was also considered, though the lifetime of such marking is short. Better use of natural markers, e.g. calcifications, and the deployment of functional imaging such as MRI might help.

Dr Raj Jena gives a feedback from one of the breakout groups.

'Image Quality'

- Debate on this topic tied in with markers, which are used because therapy/treatment-room image quality clearly lags that in diagnostic imaging. Improvements to reconstructive imaging would be limited by the need to keep X-ray doses low for repeated use during radiotherapy. System image quality, determined using idealised test objects, was identified as being different to clinical image quality using patients: anatomical site dependency was expected. What made a good image was unanswered, but it was observed that this would be context dependent. The expectation was quality related to clear boundaries, though tumours don't necessarily have these. Cone beam CT grey scale correction was already well researched with treatment planning applications of 'corrected' cone beam CT volume scans operational at e.g. The Christie.
- It was suggested that at one end of the spectrum the success of segmentation algorithms might be used as a surrogate measure of image quality, i.e. segmentation parameter adjustment might make little difference in high quality images. At the other end of the spectrum, the visibility of changes to expert clinical users might be measured in the context of expert inter-observer variation. It was noted that a single image might not have a single 'quality' throughout the grey-scale volume, especially cone beam CT and MRI. It was noted that the stability of image quality in and around the target structure to be segmented mattered most in radiotherapy. Other image modalities were mentioned, e.g. optical and ultrasound images.

'Physical and anatomical impact/changes'

- Discussion took place in the context of the interaction between tumours and organs e.g. the prostate/bladder/rectum triplet, where a change in one organ affects the other. A change could be natural filling that induces collective movement and deformation. Again, the issue of tissue loss and gain was raised as problematic e.g. a child may gain weight during the course of treatment, or a head and neck patient may lose fat and muscle around the treatment site.
- At the microscopic end of the scale, it was noted that biomechanical changes to cells under radiation insult were uncharted.
- At both the macro and micro levels there was a dependence on successful segmentation and deformable modelling, and the need for a ground truth for evaluation purposes, if progress was to be made in understanding physical and anatomical changes objectively. In turn this linked through to the need to establish correspondence and improve clinical image quality. One delegate suggested that the combined problem might need 20 years to solve.
- A reality check came from clinical colleagues whose primary concern was how much current treatments are degraded by changes from the treatment plan. How significant is this and do the benefits justify going to great lengths to measure and then compensate for patient changes? It was suggested that this question should be considered first, before undertaking any technical research projects.

Dr Gillian Whitfield gives talk "The Model Patient"

SESSION-2

Simulation and modelling from limited, noisy & dynamic data. The information we collect is imperfect, often incomplete, but it is reduced to the structures we use to make critical decisions: patient positioning, target tracking, treatment planning adaptation, etc. We see a patient many times.

a. Can we use prior knowledge and models to complete our information and improve the reduction process?

b. Can we track tissue sub volumes to summate delivered dose?

c. Is statistical shape modelling more than an aid to segmentation and something we can use to model the treatment environment ?

d. Would modelling interacting structures make treatment (re)planning realistic and dynamic?

e. Do we have enough confidence in our data and models to predict tissue and organ deformations or tumour target trajectories for aggressive X-ray and ion-beam treatments?

f. Can other patient and treatment information be fused to predict treatment uncertainty?

Keynote Talks

'The Model Patient'
(Dr Gillian Whitfield, Clinical Oncologist, Academic Radiation Oncology Dept Manchester University, Christie Hospital, Manchester, UK.)

ABSTRACT

The model for radiotherapy planning and treatment delivery is far from the ideal of multiple, interacting, sequential structures describing and predicting intra and inter fraction changes in the patient. Given the recent advances in treatment delivery and the move towards adaptive radiotherapy, such a model might be expected to be replacing the single, static, pre-treatment model advised by ICRU over a decade ago. However, there are good reasons for the lack of progress, not least the quality of image data available to radiation oncologists for delineation and structure definition. Cone beam CT is now available in the treatment room but has relatively poor grey scale characteristics compared to the fan-beam CT images used for treatment planning, which in turn cannot match the contrast detail of the MRI scans commonly used to stage disease. Even if the quality of these modalities could be improved there would still be the problem of the lack of specificity where tumours are concerned i.e. disease rarely has an inherently different signature to healthy tissues. Worse still, tumours are often diffuse and without an obvious boundary. Uncertainties in tumour position and delineation are key reason for today's relatively crude concepts of tolerance margins. Perhaps the first step to overcoming these obstacles would be to develop user weighted delineation/segmentation that takes into account microscopic spread from the bulk tumour and the disease spread pathways beyond that, all modulated by other indicators such as assay data. Unfortunately, the underlying measurements and joint structural modelling of these features is much neglected. Indeed, the display and ready navigation of the diverse raw data itself is currently impossible. The model patient is easier to state than to achieve.

'Four Dimensions and Counting'
(Prof Michael Beuve, LIRIS, University Claude Bernard Lyon-1, Lyon, France.)

ABSTRACT

The success of radiation therapy and in particular hadron therapy could be compromised by organ motion. Lung tumours are particularly affected by this problem, because their positions are subject to breathing motion. The talk starts with a brief introduction to carbon ion therapy, where emphasis is given to the differences between x-ray and ion beams and the importance for accurate calculation and subsequent monitoring of 4D radiobiological doses in ion beam therapies. After that the talk focuses on the description of the complete thoracic biomechanical model proposed to reduce the position uncertainty during the breathing cycle. The model is to be monitored by measured external parameters (thorax outer-surface motion and the air flow. The proposed model is based on the anatomical and physiological studies. Deformations are computed with the Finite Elements Method. Skin, ribs, pleura and intercostals muscles are modelled and their action on lung motion is simulated. The computed skin position is obtained from the ribs motion and vice versa: the ribs motion – and therefore lung motion – can be computed from the outer-surface motion.

Discussion and Breakout

i. Delegate Identified Issues

1. Automated/assisted delineation and segmentation.
2. Shape and motion: measurement of geometry intra- inter-fraction.
3. a. Dose modelling .vs. dose determination (does it matter?).

   b. Recalculation of TCP/NTCP delivered (as opposed to planned) & responding to this.

   c. Data fusion.

   d. Decision Support.

(~ ranked in order of interest. Note that ranks 3-5 are considered collectively within Decision Support.)

ii Feedback from Breakout groups

'Automated/assisted delineation and segmentation'

- This topic was of significant interest given the rapid increase in 3D and 4D imaging in image guided radiotherapy. In particular the limited success of existing algorithms, when used on routine medical images, was noted by clinical researchers. The opinion was expressed that segmentation algorithms in the laboratory had not reached the clinical environment because of lack of awareness, and that a suite of alternative algorithms might be useful: the huge number of papers in the literature testified to the effort being expended in this area. An alternative view was that segmentation models were immature and too data/case specific.
- 'Poor' image quality, even how to define this for clinical images, was seen as hindering machine segmentation. However, it was noted that medical experts could segment tumour structures manually despite the lack of a clear boundary. Despite inter-observer variability, clinicians were content with the outcome of subsequent radiotherapy. This suggested that accurate segmentation of tumours in particular may not be so important. In this context meta-data analysis of outcome versus segmentation would prove the point one way or the other.
- Shape priors, modelling individual expert delineation characteristics, 'areas of suspicion' and indicators of segmentation reliability were the subject of discussion. Machine assisted segmentation rather than automated segmentation attracted support. It was noted that model based segmentation had already been incorporated into commercial products. However, they only worked well on good, diagnostic quality images that showed well defined organs at risk, not tumours. Editing 'nearly correct' segmentations could be as time consuming as manual delineation itself. This left direct manual delineation dominating radiotherapy treatment planning. Adding extra information by combining multiple imaging modalities and improving both visualisation and user interaction was suggested. Methods of enhancing the tumour target were again considered: contrast media, antibodies and the like.

'Shape and motion: measurement of geometry intra-inter-fraction'.

- The interaction of anatomical structures and filling/collapsing structures like bladder and rectum was seen as highly challenging. There had been some progress with periodic and quasi-periodic motion measurement and some modelling of respiratory motion was reported in the keynote talks. It was also observed that shape-change and motion modelling, their impact on margins, was nowhere near being an automated part of radiotherapy treatment planning. Simulation of anatomical motion/interactions had not progressed to the stage of useful predictive modelling. Transient motion, loss/gain of tissue etc. were again highlighted as obstacles in modelling.

'Decision support, including data fusion, dose modelling .vs. dose determination (does it matter?) and recalculation of TCP/NTCP delivered (as opposed to planned) & responding to this.'

- The introduction of functional imaging such as PET and MRI in radiotherapy was seen as being complementary to morphological imaging, particularly in treatment planning. However, there was the problem of reconciling two different sets of data and what they actually represented: Can we easily reconcile the CTV on PET with the CTV from MRI? It was noted that PET images at the moment are low spatial resolution and introduce only indirect evidence of cancer, e.g. via FDG highlighting of elevated glucose metabolism. Even correct display selection (windowing) of PET images can be challenging.

Delegates listen to the keynote talk

- It was noted that when changes from the treatment plan are observed, the clinician needs to decide how significant these are and then take appropriate action. Sensitivity analysis of a treatment plan was thought to be of value, e.g. the effects of motion, margin changes, and beams out of spatial tolerance. The effect on tumour control and normal tissues would be helpful. TCP/NTCP are relatively crude measures that reduce complex changes to a single number, in particular masking out spatial information. Some parameter of biological effect displayed spatially in 3D would be helpful, i.e. a local TCP-like measure. TCP/NTCP themselves are problematic because of uncertainties in parameters and the need to estimate density of clonogens, etc.
- This brings us back to dose based measures. We need to show how the delivered dose differs from the ideal, planned version. If not TCP/NTCP then what is the best parameter of treatment quality? Target coverage by 95% isodose is often used in UK. Nordic countries use mean dose to the target, which has been shown to be well correlated with outcome. A better knowledge of how sensitive overall outcome is to the various changes that occur (to the dose distribution) is needed. This data is missing or incomplete due to the difficulty of collection: it takes decades. It was observed that outcome data is often incomplete even though there are national and international guidelines for this: data can be subjective rather than objective. The current evidence base was considered to be inadequate. Machine learning/analysis based on the available data was suggested. Short term effects may be more feasible to measure, e.g. acute rectal effects, and could be related to the data we gather on treatment accuracy.
- There was some discussion of adaptive radiotherapy and what to do if changes are identified during treatment. In adjusting a treatment plan should account be taken of previously delivered dose? This question remained open, except to say that this would require tools to accumulate the previously delivered dose and then incorporate this into re-planning of the adapted treatment. Machine assisted decision support was suggested. However, the clinical view was that expert decisions on patient care are multi-factorial and it was not felt that it would be possible or appropriate to try to support all of these decisions. This might diminish the scope for professional judgement.

SESSION-3

New Technologies and Analytical Methods for Preparation and Follow-up. Whilst we know a great deal about the biochemistry of cells, we know very little about their physical characteristics, even less when they form tissues. During and after treatment, we rarely follow up or assess in detail the impact of irradiation on body functions, even though we expect a range of direct and indirect side-effects.

a. Could cell biomechanical studies improve basic knowledge and treatment?

b. Can we characterise the physical properties of patients' cells and tissues prior to treatment?

c. Is it possible to develop measurement technology to support expert monitoring of tissue reaction during treatment?

d. Are there new forms of physiological measurement and signal analysis that we can use to follow post treatment recovery and late effects?

e. Where are the normal reference standards?

Professor David Burton hypothesizes about cellular biomechanics as a new opportunity in radiotherapy.

Keynote Talks

'Ion Foundations'
(Prof Jacques Balosso, University Hospital of Grenoble, Grenoble, France.)

ABSTRACT

This talk describes the past, present and the future of the Espace de Traitement Oncologique par Ions Légers dans le cadre Européen (ETOILE) project. ETOILE is aiming at building French national centre for ion hadron therapy. The talk starts with a brief historical note on the background of the project. Subsequently basic principles of the hadron therapy, an advanced radiotherapy technique that employs charged particles - most often carbon ions, are given with the comparative analysis of the x-ray, proton, electron and carbon ion beams. Subsequently the talk focuses on the present status of the project including description of clinical, technical, funding, and management challenges. Finally the talk ends with the description of the future activities of the project.

'New Modalities'
(Prof Jean Michel Moreau, LIRIS, University Claude Bernard Lyon-1, Lyon, France)

'Cellular Biomechanics - A New Opportunity in Radiotherapy?'
(Prof Dave Burton, General Engineering Research Institute, Liverpool John Moores University)

ABSTRACT

It is well known that cells affected by cancer have a disrupted cytoskeletal structure. It is also known that amongst other aspects, the cytoskeleton has a role in determining the mechanical integrity and strength of cells. Recent advances in biomechanics have made it possible to determine the mechanical properties of cells, by using techniques such as atomic force microscopy.

This paper presents a new mechanical model with which force/deflection curves obtained from populations of healthy and transformed cells are analysed. This results in the first evidence that cancerous cells do indeed appear to have different mechanical properties when compared to their healthy counterparts. This result raises a number of possibilities; firstly could such a mechanically-based test be used as a new form of quantifiable assay? Secondly, could radiotherapy be customised to best exploit this knowledge, by 'tuning' energy levels to vulnerable windows in the cell's mechanical make-up?

Discussion and Feedback

i. Delegate Identified Issues

a. Real-time Control

b. In-vivo Dosimetry

c. Cell Characteristics

d. Simulation
- Better preparation.
- Better prediction.
- Holistic – integrated approach.
- Communication and Understanding – Decision Support
- Data fusion.
- Radiobiology.

(~ ranked in order of interest. The link between Simulation and Decision Support in Session-2 was noted)

'Real-time control'

- Potential value was identified for ion-beam treatment and was highly ranked prior to breakout. However, the breakout groups did not discuss this issue in comparable depth. It was noted that commercial X-ray therapy devices like Cyberknife have this kind of control, largely because of the small and critically positioned target volumes the machine is used to treat. Some work is being done at the European level, within the MAESTRO project, working towards the live control of patient couch position.

'In-vivo dosimetry'.

- More biologically relevant dosimtery might be relevant c.f. a reduction in antibodies. It was suggested that a chemical compound could be used to tag cells: this would be altered in some way by radiation in a predictable way and be assessed non-invasively eg PET tracer where radiation causes a dose dependent disassociation of the tracer, or just the radiolabel, from cells.

'Cell Characteristics'.

- It was noted that biomechanical characteristics of cells are largely unknown, and the impact of radiation upon them. A note of caution was sounded that individual cells did not necessarily directly relate to disease in the form of a viable tumour. Nevertheless, a better understanding of cell bio-mechanics might lead to new disease diagnostics, disease localisation and therapy response monitoring. It was speculated that treatment might exploit cell biomechanics, e.g. differential resonance to ultra-sound, particularly where a tumour was superficial.

'Simulation'

- Discussed extensively. However, whether or not software modelling and simulations would ever be accurate enough for predictive use in the clinic was an open question, given so many scenarios and variables. In-vitro simulation was cited as the main objective, running across the entire radiotherapy process.
- In the biological/tissue treatment-customisation context, interest ranged from genetic screening, histology, blood flow etc. to tumour growth/response/regression. The use of DNA matrices, 100-200 genes, could indicate the appropriate, i.e. effective, radiotherapy mode for a particular individual if they were incorporated into simulations. It was suggested that there is a clear need to pre-identify tumours that are more prone to responding, rather than simply identifying the response after treatment. Likewise we need to do the same for normal tissues: if a tumour is more sensitive to irradiation, then is a healthy organ in the treatment path too? The prediction of long term reaction was seen as a neglected area. The move away from population-based treatment to sub-group and individually tailored treatments was a particular clinical ambition.
- In the physical context, the incorporation into simulations of motion, physical changes and tumour growth was seen as being important. This had to be based on actual data, e.g. informed by physical resections for CTV margins, spread fall-off patterns, which was then fed into tumour models for treatment planning. Clonogen fall-off outside the gross tumour is one big unknown, and is important because it determines treatment 'error' margins; likewise invasiveness and spread pathways could be important.
- The lack of data and tools for simulation was seen as important. The combined use of multi-modality imaging, morphological (CT, PET, MRI) and functional (PET) needed to be explored in the context of particular treatment plans and their recorded outcome: tools for multimodality manipulation are underdeveloped. However, it was noted that outcome data includes far more subjective than objective material, prime examples being for toxicity and palpable tissue changes seen in the breast. Standardised protocols are available for outcome recording but their take-up is patchy. Academic delegates wanted greater access to data and suggested web based databases. Clinical delegates noted the cost of data collection, ethics and legislative controls. A practical obstacle to data sharing was the complete lack of standardisation and infrastructure. However, it was noted that various national health services and their research institutions were investing heavily in this area.
- A reality check was injected by clinical delegates who suggested that much research might not be supportable because, whilst interesting, it would clearly not benefit oncology/patients by increasing cure and/or reducing treatment complications.

Post meeting feedback

All attendees at the Mottram Hall workshop were asked to complete a questionnaire after the meeting, in which they rated the success of various aspects of the event. The responses were overwhelmingly positive. A selection of the comments received is reproduced below.

"It has been a very successful meeting."

"The covered topics are very interesting and challenging."

"All of the sessions were very well informed with regard to the scientific state-of-the-art and clinical practice."

"It also helped to build up a network of people from different disciplines and establish co-operations."

"That kind of brainstorming is of primary importance for future collaborations at medium or large scale."

"Meeting with different scientific areas not necessarily connected to medical research to develop common strategies was definitely very positive"

"There were clearly people interested in collaborating present."

"Discussion in break-out groups did show up interesting new aspects."

"Breakouts were very interesting occasions for informal discussions, favouring both clinical pull and technological push."

"The syndicate sessions were particularly helpful in developing practical ideas for new research."

"Efficient and fast collaborations seem possible."

Project Outcomes

The primary objective of the ECSON project was to create an effective research focus around radiation therapy by establishing a European Network of academic, research, commercial and clinical institutions working in this area or having specific scientific knowledge or skill sets which could be utilised in radiotherapy. Before examining the outcomes of the project for all the project objectives outlined in the introduction of this report, it might be useful to quote some numbers which give some indications of the effort undertaken on the project and the results it generated. In total during the project ECSON has engaged with 24 different academic, research, commercial and clinical institutions from 6 European countries. ECSON has organised seven small, usually one-day, workshops throughout the duration of the project and one major three-day workshop with 43 delegates participating from 21 different institutions, that took place towards the end of the project. There have been nine seminars given at different participating institutions. ECSON supported seven short-term (typically three-day) visits and 9 longer term visits (from one week to five months) between participating institutions. As a result of the various collaborations, made possible by the ECSON project, ten papers have been published or accepted for publication, one has been submitted and a number of others are being prepared for publication. The ECSON activities have resulted in three invited presentations (including national and international conferences), and were instrumental in securing additional resources from partners' internal institutional funding to support further activities of the network. In addition, there are currently two very significant grant applications being prepared for the EPSRC and FP7 as a direct consequence of the activities undertaken on the project.

The outcomes of the project, among others, are disseminated, through the project website **www.ecson.org**. In particular, the contributions made by partners have led not only to presentations which are accessible from the resources section of the project website, but also to unique data sets and software that have been made publicly available. This project website will continue to support the network.

For the objective of supporting, the core partners have been greatly benefited from the network in developing metrology based approaches to radiation therapy, through cross-fertilisation of ideas and knowledge sharing with the network members. This was achieved by exploring different approaches to solving similar problems at different partner institutions. Particularly instrumental in realizing this objective were the short workshops and placements of staff and research students. A good example of this type of the outcome include the collaborative work on development of a new framework for deformable segmentation by combining statistical shape model and active contour implemented using the level set methodology [11]. From the scientific viewpoint, this framework is highly flexible as it enables the use of any evolution model in the image space and wider class of shape descriptors with possibly different dimensionality reduction methods applied in the shape space. From the clinical application perspective, the work is leading to a joint deformation model of the bladder, rectum, and prostate which would be subsequently used for improve monitoring of the prostate position from very few X-ray projection images. Another good example is the joint effort on comparative analysis of different registration methods [8]. Although significant amount of work has been done in this area, the assessment of these techniques in terms of accuracy for registration between radiotherapy treatment CT and cone beam CT has not been investigated in depth. The work is leading to a systematic validation process of deformable registration techniques in the context of this clinically important radiotherapy problem.

For the objective of complementing, the network established a multidisciplinary and interdisciplinary forum for sharing and transferring scientific and clinical knowledge and skills that were present at partner institutions, thereby enabling network collaborators to benefit from high-calibre research carried out at the network member institutions, with their different clinical applications. Network workshops were particularly instrumental in achieving this objective. This culminated in the three-day network workshop at Mottram Hall with 43 delegates from six countries representing 21 different academic, research, and clinical institutions. The workshop provided not only an excellent platform for knowledge sharing but more importantly it facilitated discussions which generated a comprehensive list of scientific as well as clinical questions for the future of radiotherapy, with complete coverage of the process, from treatment preparation, through treatment delivery, to patient follow-up, and in doing so spawned a huge set of new ideas!

For the objective of extending, the network has not only broadened the research carried out at partner institutions and enriched scientific knowledge, but also was instrumental in opening new application areas for existing technologies. Examples include extending segmentation methods that were previously developed for radiation therapy to the segmentation of cardiac tagged MRI images for more accurate segmentation leading to subsequent estimation of myocardial deformations [2, 10], ophthalmopathy diagnosis by providing a more automated and robust tool for segmentation of optical nerve, muscles and orbital fat [1, 3, 7], and articulated bone segmentation enabling validation of the ribcage kinematic model against real movement.

For the objective of utilising, a formidable network has been successfully established, providing a breeding ground for cross-fertilisation of ideas and for relationship development leading to technological advancement. For the former, the workshop's roundtable discussions turned out to be very productive in defining future challenges for engineering, computational and clinical sciences. For the latter, old collaborative research links have been re-energised and new collaborative links have been established on national and international levels. The strength of the network manifested itself in funding acquired by different participating institutions as a direct result of the participation of these institutions in the ECSON project (see the list of secured funding). Furthermore, within just a few months after the network seminar, a number of joint applications are currently being prepared, including an application for the EPSRC Cross-Disciplinary Feasibility Account which has been short-listed for a full proposal application and a European FP7 large-scale integrating project of the forthcoming call on "Optimising the delivery of radiotherapy and/or surgery to cancer patients".

For the objective of training, the network provided unique research training opportunities with placements, for PostDocs, PhD and MSc students, at collaborating institutions, giving them real experience of undertaking cutting-edge research projects in a truly multidisciplinary and multicultural research environment. Additionally the ECSON seminar programme, with nine seminars delivered at different institutions, extended participation to wider academic and clinical communities in the participating institutions.

In summary, the ECSON project has effectively led to a sustainable European network of excellence in applying computational and metrological methods to oncology.

Funding Secured by the Network Partners

£26,928 – "3D Deformable Modelling" School of Computing Engineering and Physical Sciences Research Fund, University of Central Lancashire, UK (internal funding).

€2,500 – "Investigation of medical active contour image segmentation techniques" ENSEA, Cergy-Pontoise University, France (internal funding) – to support MSc ECSON student placement.

Invited talks:

[1] Matuszewski B.J., Moore C., "*Deformable Models in Medical Image Processing; Advances in Image Guided Radiation Therapy*", Tutorial at the 15th European Signal Processing Conference, EUSIPCO 2007, September 3-7, Poznań, Poland

[2] Matuszewski B.J, "*Notes on Medical Computer Vision*", Department for Information Technology Faculty of Physics, Astronomy and Applied Computer Science Jagiellonian University, February 21-22, Kraków, Poland.

[3] Matuszewski B.J., "*Deformable models in Medical Image Processing*" Conferencja Modelowanie i Pomiary w Medycynie MPM 2009 (Conference Modelling and Instrumentation in Medicine), Krynica, 10-14 May, 2009 (in Polish)

ECSON funding has been contributory to the following publications:

[1] Breuilly M., Histace A., Portefaix C., Matuszewski B., Precioso F., "*Segmentation des muscles oculomoteurs en IRM cerebro-orbitale pour l'aide au diagnostic de l'exophtalmie*", 22eme colloque GRETSI, 2009 (in French)

[2] Histace A, Matuszewski B.J., Zhang Y., "Segmentation of Myocardial Boundaries in Tagged Cardiac MRI Using Active Contours: A Gradient-Based Approach Integrating Texture Analysis", *International Journal of Biomedical Imaging*, Vol. 2009.

[3] Histace A., Portefaix C., Matuszewski B.J., Zhang Y., "*Level set segmentation of extraocular muscles in MRI images for thyroid-associated-ophtalmology diagnosis*" 23rd International Congress on Computer Assisted Radiology and Surgery, CARS2009, Berlin, June 23-27, 2009.

[4] Matuszewski B.J., Moore C.J., "*Deformable Models in Medical Data Processing; Advances in Image Guided Radiotherapy*", Conference of European Association for Signal Processing - EUSPICO 2007, Invited Conference Tutorial, Poznań, 3-7 September 2007.

[5] Matuszewski B.J., Tamal M., Price G., Moore C. "*Diffusion Filters for Structured Noise Removal*" Annual Conference on Medical Image Understanding and Analysis, 2-3 July, 2008, Dundee.

[6] Matuszewski B.J., "*Deformable models in Medical Image Processing*" Conferencja Modelowanie i Pomiary w Medycynie MPM 2009 (Conference Modelling and Instrumentation in Medicine), Krynica, 10-14 May, 2009 (in Polish)

[7] Portefaix C., Histace A., Breuilly M., Matuszewski B., "*Segmentation semi-automatique en IRM3T des muscles oculomoteurs dans le suivi de la maladie de Grave-Basedow*" Actes des Journees Francaises de Radiologie (JFR), 2009, (in French)

[8] Shen J-K, Matuszewski B.J., Shark L.-K., Skalski A., Zieliński T., Moore C.J., "*Deformable Image Registration – A Critical Evaluation: Demons, B-Spline FFD and Spring Mass System*", IEEE International Conference on Biomedical Visualisation, MEDi08VIS, London, 9-11 July, 2008.

[9] Skalski A., Zielinski T., "Segmentation and Registration of Digital Medical Images: Processing Endoscopic Videos of Vocal Folds and Tomographic Data of Cancer Changes" *PAK*, No. 6, 2008 (in Polish)

[10] Zhang Y., Matuszewski B.J., Histace A., "*A fully automatic segmentation method for myocardial boundaries of left ventricle in tagged MR images*", 23rd International Congress on Computer Assisted Radiology and Surgery, CARS2009, Berlin, June 23-27, 2009.

[11] Zhang Y., Matuszewski B.J., Precioso F., Histace A., "*Statistical Shape Model of Legendre Moments with Active Contour Evolution for Shape Detection and Segmentation*", submitted to IEEE ICCV 2009 workshop on non-rigid shape analysis and deformable image alignment (NORDIA).

Appendix: What ECSON has to offer?

The ECSON Knowledge Base

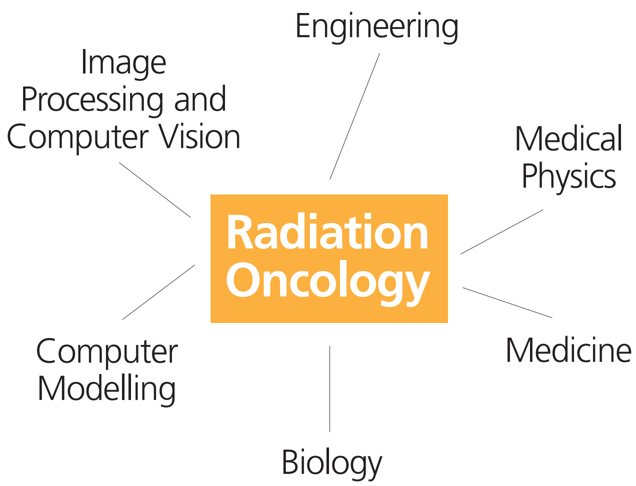
The key knowledge and skills base is offered by the three core ECSON partners as described in the supporting material for the MEGURATH project "Metrology Guided Radiation Therapy" (**www.megurath.org**). A much expanded skills base is accessible for the 'Engineering and Computational Science in Oncology Network'.

The skills and knowledge which the MEGURATH project brings together are complementary and carefully focussed. The project builds on the foundations of an established partnership in X-ray and optical image guided radiation therapy (IGRT), between medical physicists in The Christie's North Western Medical Physics Department and engineers in GERI at Liverpool John Moores University. Computational science capability from ADSIP at the University of Central Lancashire strengthens work started in earlier UK and European projects in the fields of segmentation and deformable modelling. Most importantly, these skills are brought together with a very specific practical remit of furthering the development of cancer treatment by radiotherapy. Rather than research solely for its own sake, MEGURATH involves blue skies thinking that helps to meet the challenge of building clinically useable concept demonstrators. Accountability for the research effort comes via the evaluation of integrated deliverables by clinical researchers as they conduct their own studies at The Christie, which is one of the busiest cancer centres in Europe.

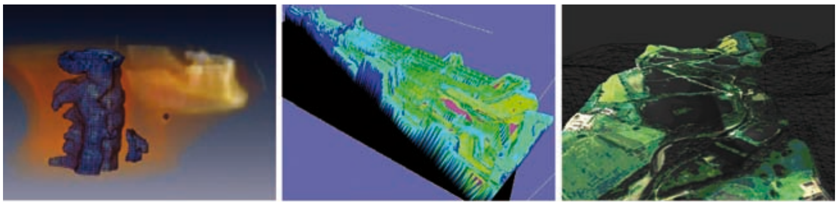
ECSON's original collaborating institutions included UCBL-Lyon, INRIA-Antipolis and OVGU-Magdeburg, all of whom have a track record of participation in challenging radiation oncology projects. With ISTI-Pisa, AGH-Krakow and Cergy-Pontoise University they offer expertise in the clinically important fields of image and signal processing, optoelectronics and instrumentation, medical physics and radiobiology. The Universities of Coventry, Bath, Manchester and Bournemouth offer expert input for the rapidly developing fields of radiotherapy control systems, image reconstruction and anatomical simulation. Emerging areas of interest were introduced by the ECSON investigators themselves, including cell biomechanical measurement, neuroscience and statistical analysis. This not only reflects a new level of multi-disciplinary activity but also the recognition that the efficacy of macro-scale cancer treatment is inextricably linked to micro-scale cellular behaviour.

The Medizinische Fakultät Universitätsklinik für Strahlentherapie (MFUS) in Magdeburg provided the direction and perspective of the research active oncologist in Europe. MFUS engaged colleagues from key institutions in Germany; notably DKFZ-Heidelburg and Dresden University Hospital. Along with eminent participation from Grenoble University Hospital, established partners of UCBL-Lyon, the European collaborators comprehensively covered hadron therapy, which is a field of research and development in which the UK currently lags seriously behind. The University of Manchester and The Christie Hospital provided active support from its Academic Department of Radiation Oncology (ADRO). Like Addenbrookes in Cambridge, oncologists at ADRO have a research track record encompassing molecular imaging and IGRT. Clinical expertise in diagnostics and related information technology came from the Jagiellonian University Medical School in Krakow.

More detailed descriptions of the knowledge and skills of the ECSON investigators and selected collaborators is sampled below. This is not intended to be exhaustive, but simply to add context to the brief survey above. By doing this the interested reader should gain an appreciation that the facilities for today's major curative and palliative cancer treatments have their basis in the physics and engineering of radiotherapy. By casting the skills net even wider across the sciences, there is every opportunity to accelerate successful research and development for oncology.



Pictures from left to right showing 3D segmentation of CT data, fusion of dual modality measurement data from an aircraft component, and 3D terrain superimposed with hyperspectral images for real-time exploration.



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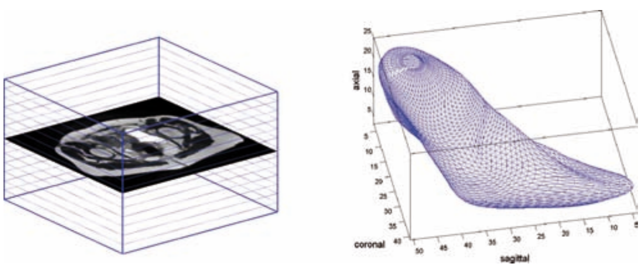
University of Central Lancashire

ADSIP (Applied Digital Signal & Image Processing) Research Centre University of Central Lancashire, Preston PR1 2HE, UK

The Centre is well known in Europe for its expertise in the development and deployment of highly sophisticated and innovative signal and image processing techniques as well as computer vision and 3D/4D technologies in various application domains. These include

- **Aerospace non-destructive testing** by working in collaboration with leading aerospace companies across Europe
- **Computer vision** with focus on 3D information retrieval from static and dynamic scenes
- **Immersive and interactive visualisation** by working with different disciplines
- **Medical diagnosis and treatment** by working in collaboration with National Health Service (NHS) Trusts in the region
- **Radiation effects on electronics** by working with world leading experts
- **Remote sensing** by working in collaboration with various universities in Atlantic Europe

There is a wide range of externally funded research projects with substantial support from EU government bodies, national research councils and industry. The Centre has involved in external funded projects with a total value of £58 millions since 2001.



Automatic surface fitting of bladder from a sequence of dynamic MR data.

A major research area in the application domain of medical diagnosis and treatment is radiotherapy. The Centre coordinates the Engineering and Computational Science for Oncology Network (ECSON), www.ecson.org, funded by EPSRC (Engineering and Physical Sciences Research Council in the UK), with partners from UK, France, Germany, Italy and Poland, and is involved in the development of metrology guided radiotherapy through participation in the MEGURATH project (also funded by EPSRC).

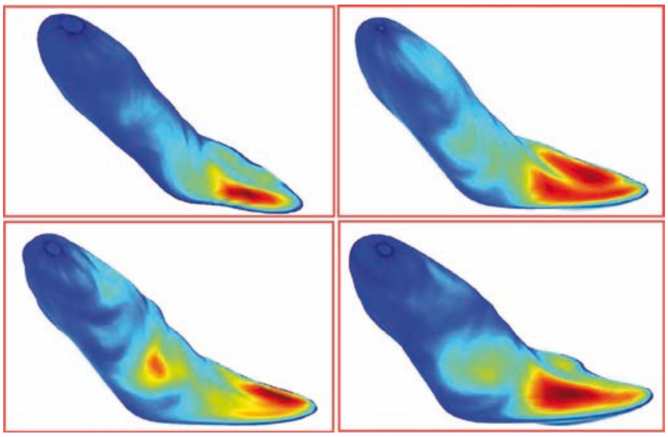
Among a range of technologies which could be of value to radiotherapy, particularly noteworthy are:

Image Segmentation

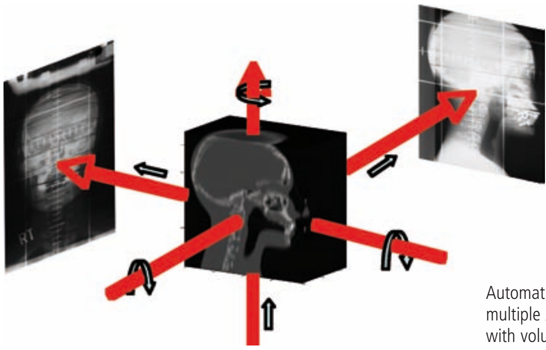
Research in this area concentrates on active contour segmentation including segmentation methods utilising prior statistical knowledge and methods inherently preserving known object/organ topology in the multiphase level set framework. More recently a number of methods have been developed using combinatorial optimisation for fast interactive 2D/3D segmentation including graph, grow, grab, and geodesic cuts.

Deformable Image Registration

Deformable registration is a key enabling technology in the medical image processing. Among others it enables monitoring of disease progress or validation of radiotherapy treatment. It is still a challenging problem and an area of the intensive research. The ADSIP centre is contributing to this effort and has developed a suite of 2D/3D deformable registration techniques including deformable registration with embedded rigid objects and methods for joint registration and segmentation with missing data.



adsip
APPLIED DIGITAL SIGNAL AND IMAGE PROCESSING RESEARCH CENTRE



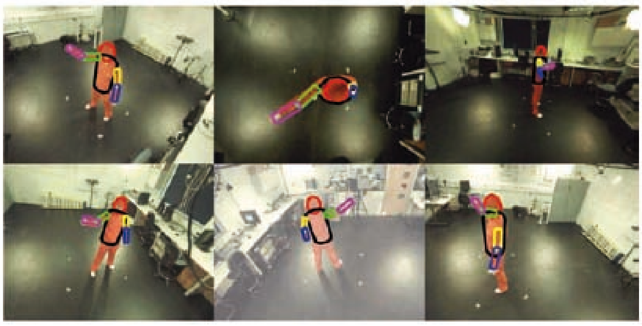
Automatic alignment of multiple X-ray images with volumetric CT data.

Accelerated Registration of X-ray Images with CT

A number of accelerated algorithms have been developed for automatic alignment of multiple X-ray images with volumetric CT data. The novel aspects of these algorithms include iterative projection of the 3D anatomical structure for rapid region based coarse alignment, identification of region-of-interest by the depth image for fine alignment, fast generation of digitally reconstructed radiographs, and computation efficient optimisation based on cost function behaviour. These methods have been shown to provide not only the accuracy comparable with other methods but also a larger capture range of initial patient displacements.

Articulated Human Kinematics Reconstruction

Work in this field culminated in the development of a multi-camera marker-less tracking system for estimating parameters of articulated human kinematic model. The system uses efficient implementation of the Sequential Monte Carlo methodology with a full body quaternion based articulated skeletal model.



Human articulated motion tracking from multi-camera system.

3D Face and Facial Expression Recognition

Algorithms developed in this research theme aim at development of robust face and facial expression recognition tools based on texture-less 3D face scans. As a part of these efforts the ADSIP centre has build the first 3D dynamic facial expression database.

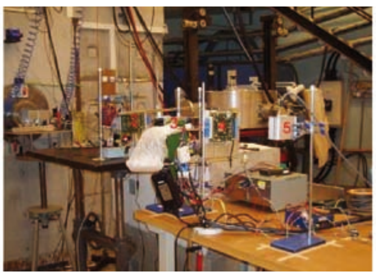
Novel Imaging Neutron Single-Event Effect Monitor

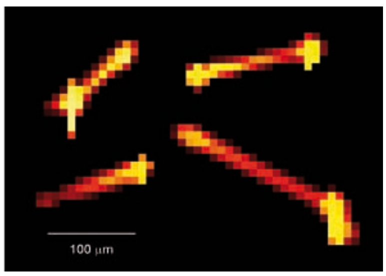
Based on a charge coupled device (CCD) sensor, a novel monitor has been developed to image directly charge packets resulting from nuclear interactions in semiconductor devices. The imaging device has been deployed in a variety of natural and synthetic neutron fields for characterisation of neutron dosimetry and validation of atmospheric radiation models. These include Los Alamos Neutron Science Center in USA, The Svedberg Laboratory in Sweden, Canada's National Laboratory for Particle and Nuclear Physics, Rutherford Appleton Laboratory, and the International Foundation High Altitude Research Stations at Jungfraujoch in Switzerland.

Other active medical related projects conducted at the ADSIP Centre include

JAAS (Joint Acoustic Analysis System)

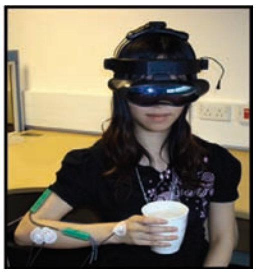
This project is funded by ARC (Arthritis Research Campaign), and is in collaboration with Blackpool, Flyde & Wyre NHS Trust and Physical Acoustics. The work has led to a new measurement system based on acoustic emission for assessing the dynamic integrity of knee joints, and the system has shown to identify healthy and osteoarthritis knees in terms of their acoustic emission profiles but also severity of osteoarthritis knees and deterioration of knee conditions due to age.





Pictures from left to right showing attitude research station at Switzerland, neutron beam with measurement set up, and neutron events detected.

Pictures from left to right showing joint movement analysis using isokinetic dynamometer, acquisition of acoustic emission from knee joints, and mulimodal biofeedback virtual reality system for hand motion rehabilitation.



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Computer-Assisted Quantification of Vascular Abnormalities

Working in collaboration with Blackpool Victoria and Christie hospitals, the project develops adaptive 3D processing methods to locate, identify and segment the internal carotid arteries from contract-enhanced magnetic resonance angiograms for accurate and consistent stenosis measurement.

Multimodal Biofeedback Based Virtual Reality for Hand Motion Rehabilitation

To improve hand motion function of the cerebral palsy and stroke patients, the project develops an immersive and interactive training environment for reaching, grasping and releasing tasks. The system includes an electromyography sensor to provide the muscle activity response, electromagnetic position sensors to track the hand and head, an electro-goniometer to provide the elbow joint rotation, and a stereoscopic head-mounted display to provide visual feedback.

Postural Stability and Gait of Knee Arthroplasty Patients

Working in collaboration with Royal Preston Hospital, the project investigates the 3D mechanics of the knee joint during a range of functional tasks following total knee placement.

The research activities in the Centre are supported by four modern laboratories equipped with a wide range of the state-of-the-art hardware and software systems for digital data capture, real-time processing, as well as immersive and interactive visualisation.

3D Visualisation Suite

Supported by EON Reality, the suite is equipped with bio-feedback with high speed and precision ultrasonic-inertia and electromagnetic tracking systems, spherical and high speed cameras, and a range of stereoscopic display systems such as head mounted display, autostereoscopic monitor, and configurable multi-wall cave.

Digital Signal and Image Processing Laboratory

Supported by Texas Instruments, the laboratory is equipped with dedicated development platforms for real-time acquisition and processing of signals and images.

Non-Destructive Testing Laboratory

Supported by BAE Systems, the laboratory is equipped with a range of non-destructive inspection systems based on acoustic emission, acoustography, ultrasound and ultrasonic phased-array.

PACCAR Robotics and Vision Laboratory

Supported by PACCAR, the laboratory is equipped with a high-speed synchronous multi-camera system, various static and dynamic 3D scanners and cameras, as well as various sizes of mobile robotic platforms and multi-axis robotic arms.

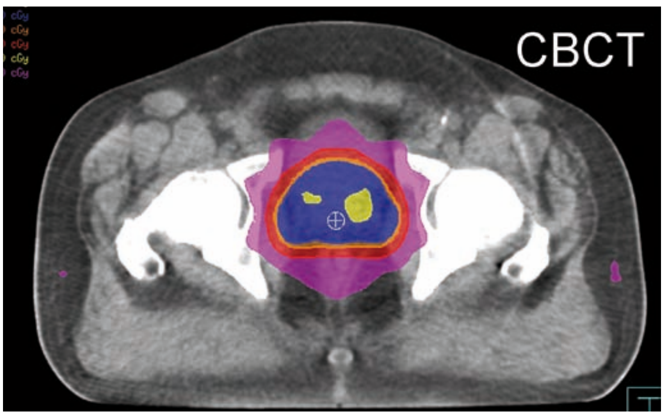
3-wall stereoscopic display environment with wireless tracking for immersive and interactive visualisation of medical data.

3d face acquired using 3dMD dynamic 3D scanner.

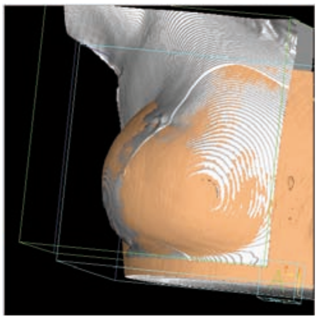
Radiotherapy Developing Technologies (DTRT), North Western Medical Physics, The Christie NHS Foundation Trust, Manchester, M20 4BX, UK

The Developing Technologies research directions, measurement guided preparation, delivery and follow-up in radiation therapy, grew from the multidisciplinary, collaborative foundations laid in European projects INFOCUS and ARROW. A boost came in 2002 with the opening of the Wade Research Centre and its dedicated radiographers, and the Academic Radiation Oncology group.

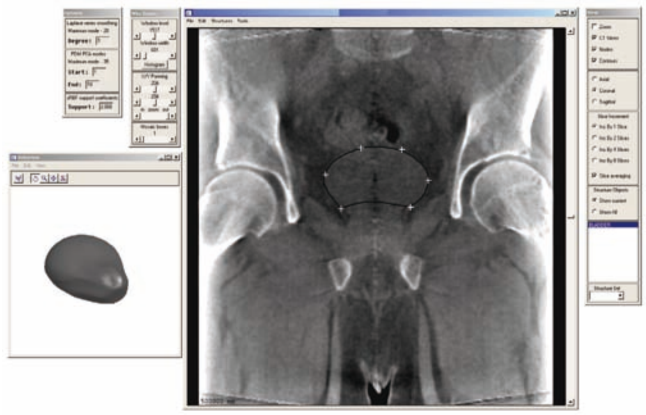
The primary aim has been to move towards seeing and measuring a treatment as it is given, dynamically in 3D, including during irradiation; to ensure setup and delivery to plan, provide the 4D evidence for tumour targeting and treatment adaptation, and improve understanding of the impact of changing patterns of motion and shape on treatments. The persistent problem of tumour and organ delineation was addressed in EPSRC SCULPTER, focussing on the capture of expert clinical knowledge using 3D statistical shape modelling, and securing the section an NHS Innovation Award. 'No dose' dynamic optical body surface sensing has been researched in combination with a 'low dose' development of 3D X-ray cone beam CT (CBCT) image guided radiation therapy (IGRT), helped by industrial funding from Elekta.



Re-calculation of delivered dose using corrected CBCT



Comparison of CBCT and optical surface data for treatment planning



SCULPTER user interface

A method of assessing the impact of measured body surface and organ deformations on conformal treatments has been demonstrated for rectal cancer and, most recently, developed for breast IMRT in the Wade Centre using CBCT IGRT. Studies of speech and endocrine perturbation following radiotherapy attracting US collaboration were aimed at objectively tracking patient recovery, targeted intervention/rehabilitation and rationalisation of treatment techniques. With the effects of herceptin in mind, the underlying science has been extended for the analysis of MUGA scans for perturbed ejection fraction.

The timeliness and foresight that has characterised the section's research between 2002-2007 can be judged from the 2007 report of the Technology Subgroup of the UK National Radiotherapy Advisory Group. On future technological developments and requirements within the next 10–20 years, it stated that optimised setup is essential for accurate treatment and is likely to benefit all RT patients. It recommended further evaluation of optical imaging systems, which do not incur X-ray exposure, as one of the strategies for reducing setup variation. It also stated that 4-D adaptive IGRT should become the standard of care within 5-10 years.

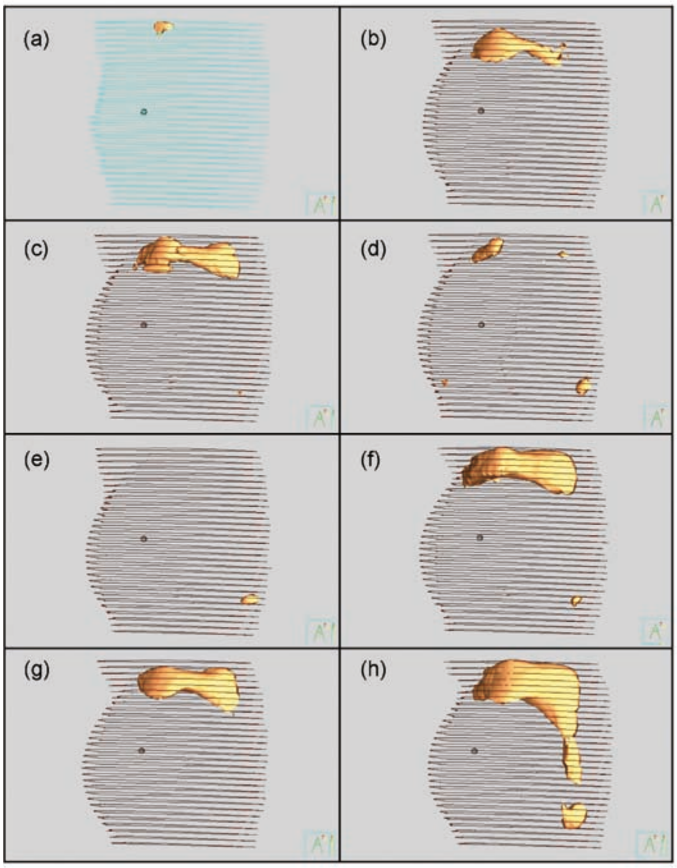
Selected highlights are as follows:

X-Ray Image Guided Radiotherapy

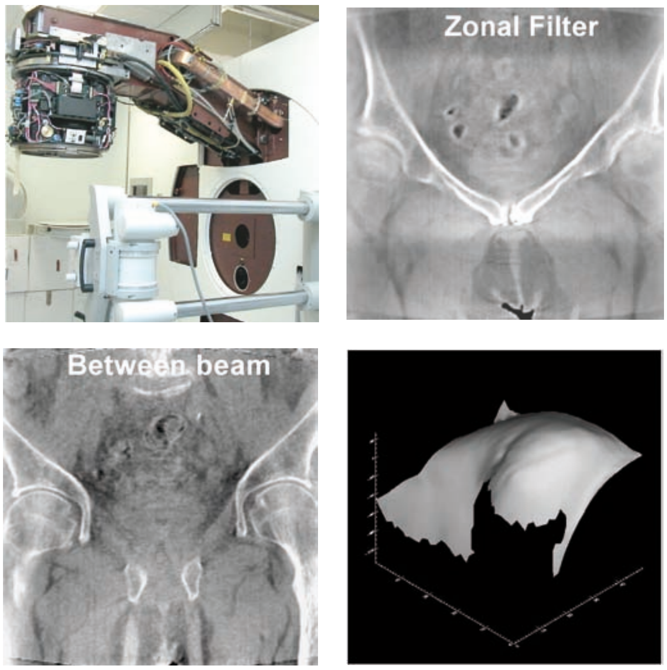
Working on one of only four prototype Synergy X-ray IGRT machines from Elekta, a 'lowest dose fit for purpose' approach showed that, for bony setup, only a fraction of the X-ray exposures theoretically needed for full CBCT reconstruction was needed with automated 3D matching to planning scans; and that frequent, fast scanning was feasible within accepted dose constraints. A 'zonal filter' was invented to reduce patient dose and improve soft tissue contrast by physically preventing scatter. Using prior knowledge, CBCT reconstructions have recently been grey scale corrected for treatment re-planning and improved soft-tissue visibility (patent pending Moore & Marchant). For patient imaging during beam delivery, 'between-beam' CBCT was invented. It uses the redundant time arcing between treatment beam positions.

Dynamic Measurement with Optical Sensing during Irradiation

A custom designed optical body sensor produicing dynamic, 3D body and skin texture maps, was used to follow positioning and motion during irradiation at every fraction of breast IMRT and CBCT scanning. 'The' body surface for a radiotherapy fraction has been defined as the mean surface generated by the sensor over several breathing periods. Inter-fraction variation of the mean surfaces and corresponding texture maps suggest the shape and setup of the breast are unexpectedly variable. Intra-fraction motion about the mean surface is often of centimetre order, and can be spatially anisotropic. Initial results suggest that the reduction of hot spots by IMRT may not be as great as expected, and the development of significant cold spots should be anticipated.

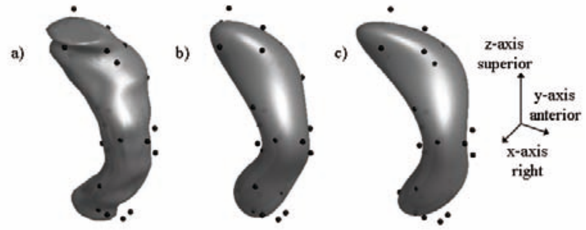


Daily position of dose hotspots during breast radiotherapy based on CBCT, from [1]



CBCT development work, from [2], and in-treatment optical surface

Analysis of rectal shape variability, from [3]



The Christie NHS
NHS Foundation Trust

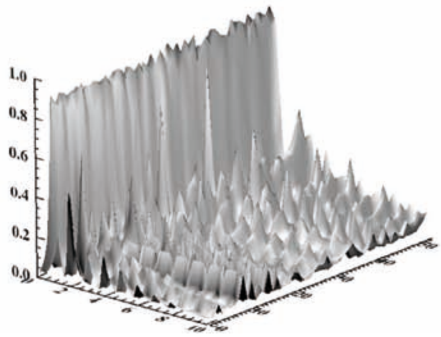
Structure Creation Using Limited, Point Evidence in Radiotherapy

Radiotherapy delineation has remained subjective, failed to capitalise on prior knowledge and is ill suited to the avalanche of poor quality CBCT emerging from the treatment room. In this project the evidence needed for constructing a 3D target or organ was reduced to a sparse cloud of interacting, clinically defensible points. Compactly supported radial basis functions allowed points to interact, analogous to varying the elasticity of the surface. Variable 3D detail was provided by changing the number of spherical harmonic coefficients included in an advanced statistical shape model, developed from archived expert data. The model was used to differentiate organ motion from observer variability and to explore the calculation of coverage probabilities for evidence based ICRU radiotherapy margin generation. At a pragmatic level, observers were able to produce more consistent, reproducible 3D delineations faster with SCULPTER than conventional contouring.

Automated Voice Quality Monitoring for Differentiating Cancer Therapy, Recovery Patterns & Rehabilitation

Definitive single parameter characterisation of voicing was achieved using spectral pattern approximate entropy (ApEn), with two normal groups discovered, one characterised by incomplete closure of the vocal folds and a low, almost pathological ApEn . Tracking larynx cancer patient recovery with ApEn showed that early stage cases reached at least lower level normal voicing, explaining speech and language therapist categorisation of 'entirely normal voicing'. Older, later stage patients showed reduced ApEn and voicing deterioration. During the project ApEn was also deployed to assess growth hormone deficiency (GHD) in adult endocrine patients, some treated, others not. The data were compared to those obtained from genetically compromised individuals during their stop-over in Manchester en route from Sindh, Pakistan to Chicago. It was shown that tentative evidence existed for the early detection of GHD purely from ApEn analysis of voicing.

Spectral analysis of voice quality following larynx cancer therapy



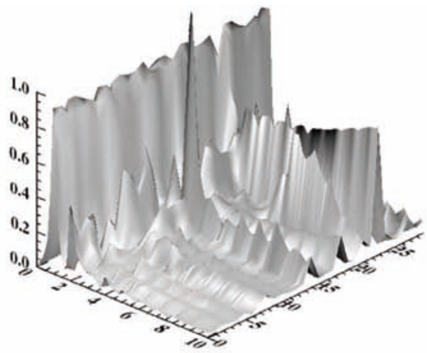
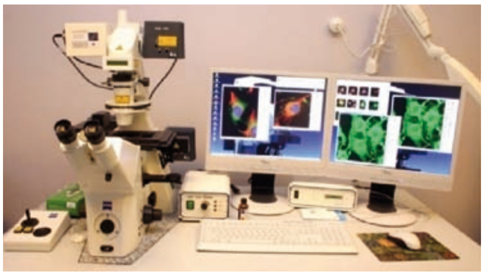


Image references

[1] Jain, et al., 2009, Inter-fraction Motion and Dosimetric Consequences during Breast Intensity Modulated Radiotherapy (IMRT), Radiotherapy & Oncology, 90 93-8.

[2] Moore, et al., 2006, Developments in and Experience of Kilo-voltage, X-ray Cone Beam, Image Guided Radiotherapy, Image Guided Radiotherapy, British Journal of Radiology, 79, S66-S78.

[3] Price and Moore, 2007, A method to calculate coverage probability from uncertainties in radiotherapy via a statistical shape model, Physics in Medicine & Biology, 52(7) 1947-1965.



GERI's Zeiss Scanning Confocal Microscope

CEORG Sub-Division of GERI Liverpool John Moores University, UK

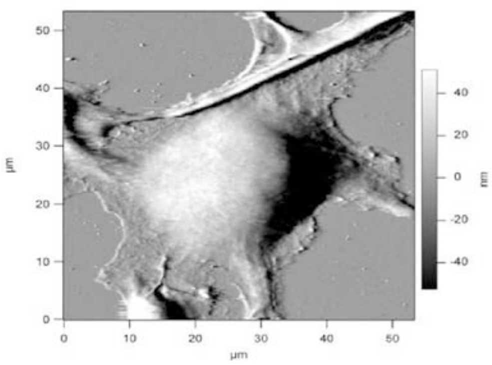
Introduction: What is now the CEORG Sub-Division of GERI at Liverpool John Moores University was originally founded in 1972 as the Coherent and Electro-Optics Research Group (CEORG) and expanded to be one of the most successful research groups at the University.

It has an international reputation for its contributions in the fields of applied optics, precision measurement and particularly in fringe pattern analysis.

Much of this research activity is funded by the European Commission's Research Framework Programmes (e.g. ESPRIT, BRITE-EURAM and BIOMED), or by the UK Government (from EPSRC and the Teaching Company Directorate) and also locally (from the Merseyside Objective 1 funds and local industry).

Over fifty research students have gained Ph.D.'s and other higher degrees from CEORG. The group has produced hundreds of publications in learned journals and at conferences. The group also has significant experience in writing research grant proposals and in the management and co-ordination of large-scale research projects, both at national and European level.

The main area of interest of the CEORG Sub-Division of GERI lies in applied research, divided between medical and industrial fields, however the Division also carries out some blue-sky research.



Primary lung fibroblast imaged by AFM

Expertise:

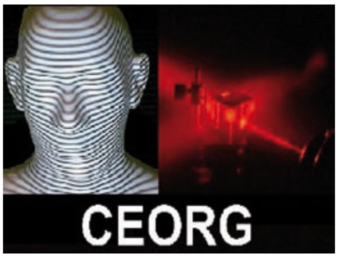
- 3D Metrology
- Image/Signal Processing
- Applied Optics
- Fringe Projection/Analysis Systems
- Interferometry
- Fibre-Optic Sensors
- Phase Unwrapping
- Classical & Digital Holography
- Atomic Force Microscopy
- Confocal/Fluorescence Microscopy
- Laser Tweezers / Optical Trapping / Micro-Manipulation

Fringe Projection/Analysis

- GERI design & build bespoke Fringe Projection systems and write the associated Fringe Analysis and phase unwrapping software
- High-Resolution (0.25 to >1 Mpix)
- Offers Full-Frame 3D measurement at near real-time performance
- Typical Accuracy 100 - 300 microns
- Expertise in System Modelling & Advanced Calibration Strategies
- Multi-Sensor Intelligent Systems
- Dynamic Object Measurement

Mini-Case Studies:

As an illustration of the way in which the CEORG Sub-Division of the Institute applies its research to specific projects, we will now give two mini-case studies of typical research projects conducted at GERI.



Case-Study 1: Cell Mechanics

The Institute has engaged in some blue-sky research into investigating the Bio-mechanics of living human cells and has an on-going interest in this field.

The Institute has already completed a Ph.D. in this area and has invested significant capital resources in the fields of nano-scale and micro-scale imaging, including a new Asylum 3D atomic force microscope with thermal stage, acoustic enclosure and active anti-vibration table, a new Zeiss confocal microscope and the development of a new fibre-optic based optical trap for sample restraint and micro-manipulation of cells.

The cell mechanics special interest group is a multi-disciplinary team, drawn collaboratively from GERI and life-scientists at LJMU. It has developed a novel non-linear extended Hertz model to describe cell stiffness, i.e. Young's Modulus versus AFM tip indentation. Other GERI researchers are carrying out investigations in the following related areas; micro-manipulation of cells using optical tweezers, investigating the Actin cytoskeleton that gives mechanical support to the cell and the processing and enhancement of AFM force curve data.

Several Ph.D. programmes are active in this area in both CEORG and in the School Of Biomedical Sciences. Funding for this work has come from the EPSRC and HEFCE's Science Research Investment Fund.

Case-Study 2: Human Body Measurement In Radiotherapy

The CEORG sub-Division of GERI has had a long-term interest in applying its expertise in 3D measurement to the field of patient positioning and monitoring during radiotherapy treatment. CEORG has had a long-term collaborative research relationship with the Christie NHS Foundation Trust at Manchester, one of Europe's largest cancer treatment centres. This relationship led to two large FP4 European research projects, called INFOCUS and ARROW, co-ordinated by CEORG and CHRISTIE respectively. INFOCUS laid the foundations for in-treatment 3D measurement of patients' body surfaces, using interferometric fringe projection. ARROW (Animated Real-Time Radiation Oncology Worktools) was a direct continuation of the research work that was performed in INFOCUS, with the objective of moving towards a fully dynamic treatment regime. The major contribution by CEORG in ARROW was the world first ever production of animated sequences of 3D patient motion during radiotherapy treatment. This work is on-going with two UK EPSRC funded projects called MEGURATH and ECSON. In MEGURATH GERI and the CHRISTIE are joined by a third collaborative consortium partner from the North-West of England, the University Of Central Lancashire (UCLAN). In MEGURATH GERI builds on and extends the work carried out in the two European projects INFOCUS and ARROW in order to create a new generation of 3D optical sensors for dynamic 3D patient position monitoring. The MEGURATH Optical Sensor uses an LCOS projector to project fringes in a specific separable primary colour. Several sensors are used in parallel to produce a multi-sensor intelligent measurement system that is capable of measuring a very wide field across the patient's body surface. This information may be used to correct for motion artefacts in Cone Beam Tomography and brings the potential for the first ever in-treatment tomographic imaging in radiotherapy.

ECSON, the Engineering and Computational Science for Oncology Network, aims to create an effective European research network around the MEGURATH project and further the exploitation of technology in oncology, by invitation into the network of targeted European research centres.

Other Recent Research Projects:

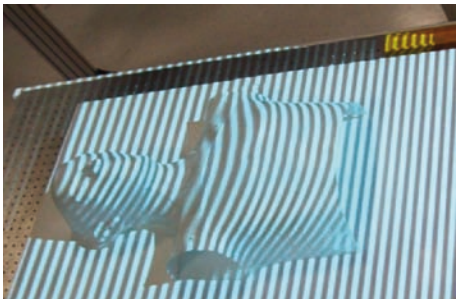
Interferometry:

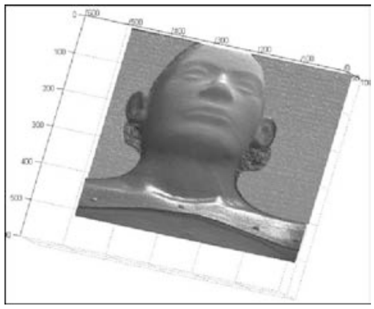
- Classical and state-of-the-art interferometry
- Electronic Speckle Pattern Interferometry (ESPI) For Vibration and Deformation analysis

Novel Absolute Length Interferometry:

- Better than 4 micron accuracy
- Not based on fringe-scanning, so no requirement for continuously visible path

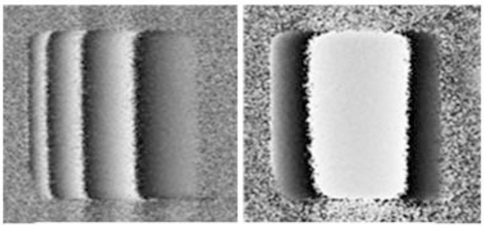
GERI's Asylum 3D Atomic Force Microscope



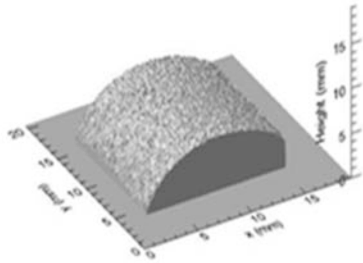


2D and 3D Phase Unwrapping: GERI has a world-class reputation in phase unwrapping. The CEORG Sub-Division of GERI has completed 6 Ph.D.s in this area and GERI's unwrappers are widely used internationally.

- The University of California at Berkeley, Helen Wills Neuroscience Dept uses our 3D phase unwrappers in their MRI systems.
- The SciPy open source library for the Python programming language uses GERI's 2D and 3D phase unwrapping algorithms.
- GERI's phase unwrappers are also used in Synthetic Aperture Radar (SAR) by both the European Satellite manufacturer EADS Astrium and the European Southern Observatory based in Australia.



Digital Holographic Dual-Source Contouring Of The Surface Of A Roller Bearing



Fibre-Optic Sensors:

GERI has significant research expertise with Fibre-Optic Sensors using Bragg Gratings, offering:

- Low Noise and High Sensitivity
- Compact Easily Integratable Sensors
- Low Cost Interrogation Strategies

Applications for Fibre Bragg Grating Sensors include:

- Temperature Measurement
- Ultrasound Measurement
- Vibration Measurement/Microphones

Digital Holography:

An emerging technology offering the advantages of full-3D wavefield holographic representation, combined with the speed and flexibility of computer-based rather than wet-chemical processing. This enables advanced analysis, such as numerical focusing at different layers of the reconstructed holographic object.

Other Recent Research Projects:

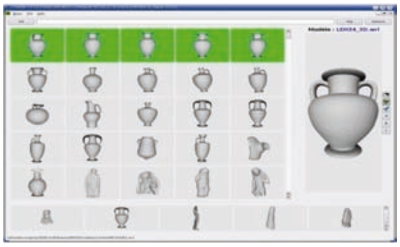
- Large Object Measurement Using Multi-Panel Methods
- Digital Holographic Microscopy
- Wavelet Fringe Analysis
- 3D Measurement Of Reflective Objects Using Reflected Fringe Projection

CEORG Research Facilities at GERI:

- Large Well-Equipped Optics Laboratory
- Holographic Darkroom

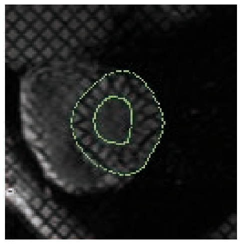
In addition to the many bespoke systems that GERI develops, the Institute also possesses a number of larger capital commercial instruments and facilities:

- Asylum Research MFP-3D-IO Atomic Force Microscope coupled to an inverted Olympus IX 50 Stereo Microscope
- Zeiss Laser Scanning Confocal Microscope LSM 510 META
- OPTONOR VibroLab1000 TV Holography (ESPI) System
- WYKO RST Plus White Light Interferometer
- UNISCAN OSP100 Laser Triangulation Sensor



3D-Shape retrieval.

Video segmentation for indexing.



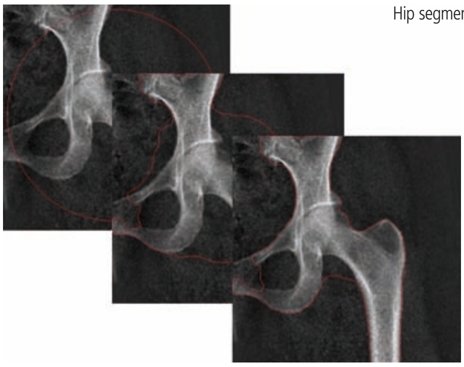
Myocardial boundaries segmentation in tagged cardiac MRI (2D+T).

ETIS (Signal and Image Processing Research Laboratory) ENSEA University of Cergy-Pontoise - CNRS, F95000 Cergy, France

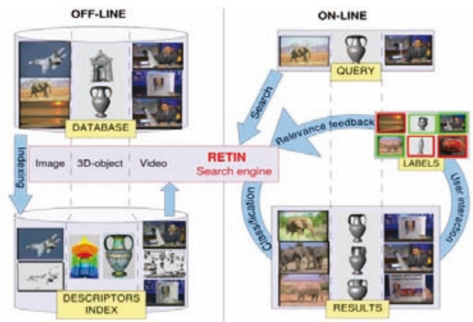
There are 37 permanent staff members and 35 PhD student currently working in the ETIS Laboratory. The ETIS is divided into four teams:

- Information, Communication and Imagery (ICI)
- Multimedia Indexing and Data Mining (MIDI)
- Hardware Design for Signal and Image Processing (ASTRE)
- Neurocybernetics

The main area of interest of the ICI team is in the: image restoration, active contour segmentation, medical data analysis and telecomunication.



Hip segmentation.



RETIN Search Engine.

The MIDI team works in the area of: image, video indexing and retrieval, interactive content search, and active learning.

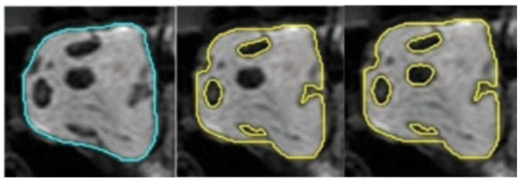
The ASTRE team expertise is mainly in the dynamically reconfigurable and adequacy architectures.

The Neurocybernetics is recognised for its research in robotics, neurobiology and psychology of development, application of learning processes.

ECSON PROJECT

ETIS has been very active in the ECSON project and benefited from number of seminars and workshops which invigorated research interest in medical image processing and enabled to reinforce existing research links as well as to establish new one. The main research actively pursued in the lab which are of relevance to the ECSON project include active contour segmentation and information retrieval. During the execution of the ECSON project particularly fruitful was work carried out, jointly with ADSIP Research Centre from the University of Central Lancashire, in the area of active contour segmentation. As a result of the bilateral visits a new research topic has been established in the active contour segmentation incorporating prior statistical shape knowledge. In terms of application areas, apart from radiation therapy, work has been done in identifying diagnostic tagged cardiac and thyroid-associated-ophtalmopathy MR images as areas which can benefit greatly from the work done on active contour segmentation.

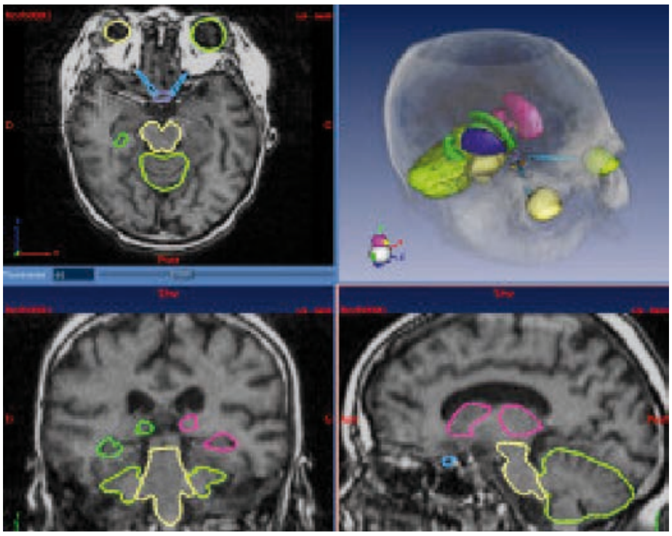
Extraocular muscle segmentation for early diagnosis of exopthalmia.



Asclepios research team – INRIA Sophia-Antipolis, France

Tremendous progress has been made in the automated analysis of biomedical images during the past two decades. For instance, for rigid parts of the body like the head, it is now possible to fuse images of the same patient taken from different imaging modalities (e.g. anatomical and functional), or to track the evolution of a pathology through the automated registration and comparison of a series of images taken at distant time instants. It is also possible to measure some functional properties of the heart from dynamic sequences of Magnetic Resonance, Ultrasound or Nuclear Medicine images.

Despite these advances and successes, one can notice that statistical models of the anatomy are still very crude, resulting in poor registration results in deformable regions of the body, or between different subjects. If some algorithms exploit the physical modelling of the image acquisition process, only a few actually model the physical or even physiological properties of the human body itself. Coupling biomedical image analysis with anatomical and physiological models of the human body could not only provide a better comprehension of the observed images and signals, but also more efficient tools to detect anomalies, predict evolutions, simulate and assess therapies.



Atlas based segmentation of cerebral organs at risk for radiotherapy (collaboration with Dosisoft).

More information is available on **www.inria.fr/sophia/asclepios**

From these observations, the Asclepios research team focuses on the following topics.

Medical Image Analysis

Despite remarkable efforts and advances during the past twenty years, the central problems of segmentation and registration have not been solved in the general case. It is our objective in the short term to work on specific versions of these problems, taking into account as much a priori information as possible on the underlying anatomy and pathology at hand.

Biological Image Analysis

In Biology, a huge number of images of living systems are produced every day to study the basic mechanisms of life and pathologies. If some bio-imaging principles are the same as the ones used for medical applications (e.g. MR, CT, US, Pet or SPECT), the bio-imaging devices are usually customized to produce images of higher resolution for the observation of small animals (typically rodents). Some of the recent advances made in Medical Image Analysis could be directly applied (or easily adapted) to Biological Image Analysis.

Computational Anatomy

The objective of Computational Anatomy (CA) is the modelling and analysis of biological variability of the human anatomy. Typical applications cover the simulation of average anatomies and normal variations, the discovery of structural differences between healthy and diseased populations, and the detection and classification of pathologies from structural anomalies.

Computational Physiology

The objective of Computational Physiology (CP) is to provide models of the major functions of the human body and numerical methods to simulate them. The main applications are in medicine and biology, where CP can be used for instance to better understand the basic processes leading to the apparition of a pathology, to model its probable evolution and to plan, simulate, and monitor its therapy. A grand challenge that we want to address in this project is the automatic adaptation of the model to a given patient by confronting the model with the available biomedical images and signals and possibly also from some additional information (e.g. genetic).

Clinical and Biological Validation

If the objective of many of the research activities of the project is the discovery of original methods and algorithms with a demonstration of feasibility on a limited number of representative examples (i.e. proofs of concept), we believe that it is important that a reasonable number of studies include a much more significant validation effort.

The general view of the Holycross Cancer Center.

Holycross Cancer Center, Kielce, Poland

Holycross Cancer Center is the one of the sixteenth provincial centres of oncology working in the network and the only one in the Holycross Province. Self-government of the province and Ministry of Health finance it. Its activity concentrates on three basic fields: scientific researches, patients care, training and education. Scientific researches are related to the basic science and clinical trials.

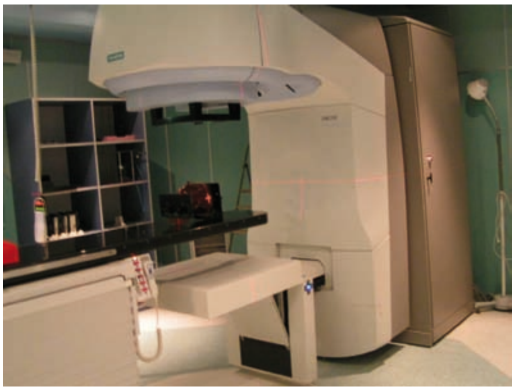
Cancer care is carried through diagnostics and treatment. The following well-equipped units fulfil diagnostics: Surgical Pathology Department, Radiology Department, Panendoscopy Division, Nuclear Medicine Division and Laboratories (Biochemical, Microbiological, Tumour Markers, Genetic and Physical Methods). Each clinical department provides clinical wards and outpatient clinics. The care of oncological patients is realised in departments: Oncological Surgery, Postoperative Unit, Intensive Care Unit, Radiotherapy, Brachyterapy, Endocrinology, Chemotherapy, Gynaecology, Oncohematology, Oncological Urology, ENT Surgery and Pallative Therapy.

Educational activity is performed in many ways, by: public education, organising courses for general practitioners, for the specialists of different disciplines and hospital training in endocrinology, chemotherapy, radiology and haematology.

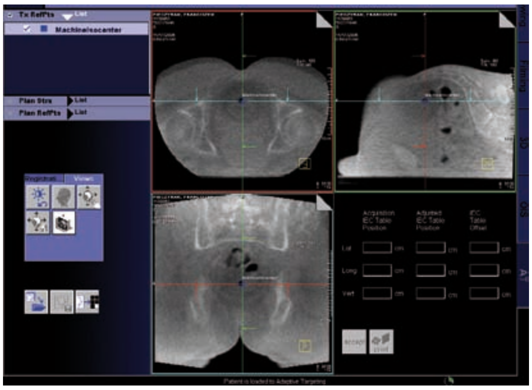
In 2008 total number of patients who were given treatment was close to 200,000 (about 15,000 in bed wards and the rest in outpatients clinics).

The Centre co-operates with different international agencies such as International Agency for Research on Cancer, European Network of Cancer Registries (member) and European Organisation of Cancer Institutes (member).

The Radiotherapy Department is equipped in three modern Siemens linear accelerators – 2 ARTISTE and 1 ONCOR. The most modern treatment techniques are applied: the Intensity Modulation Radiotherapy and the Image Guided Radiotherapy. The latter is performed with the Megavoltage Cone Beam CT and with the so called CT on rails. The IGRT is used for most patients treated with radical intent. At the preparation stage for several patients the target volume is defined based on image registration. The CT, MRI and PET images are used. In the Brachytherapy Department for some patients the treatment is performed under image guidance. For image guidance the CT and ultrasound images are used. The Holycross Center is recognized by the International Atomic Agency as a center of competence.

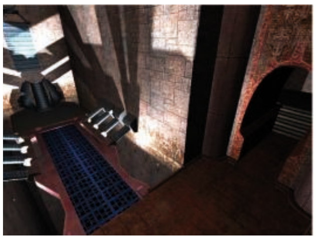
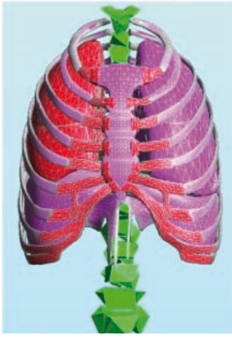
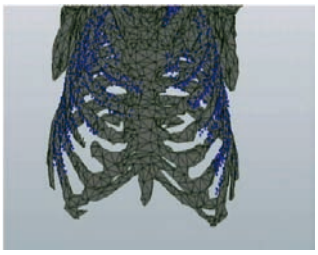


ONCOR accelerator with the MVCBCT.



Images obtained with the MVCBCT.

ONCOR accelerator with CT on rails (PRIMATOM).


LIRIS Laboratory (CNRS-UMR 5205) University Claude Bernard Lyon 1, 69622 Villeurbanne cedex, France

More than 110 permanent and non permanent members, and PhD students are collaborating within the image department of LIRIS Laboratory. The following topics are treated by the five teams of this department: geometric modelling, computational and discrete geometry, fractals, characteristics extraction and identification, video and compression, water marking, realistic rendering for mobile augmented reality, simulation, analysis and animation for augmented reality.

Simulation, Analysis, and Animation for Augmented Reality (SAARA) team

SAARA is one of five teams of image department. The research activities of SAARA revolve around augmented reality through movement analysis and quantification, with the goal to either reach physical realism through the creation of adapted simulation models, or visual realism through the analysis of static or moving scenes originating from video sequences. The research developed within the team span the following spectrum:

- extraction, analysis of the geometry, photometry and kinematics of objects in a real scene originating from images, videos or scanner data;
- reconstruction of the shape and appearance of objects, based on the above analysis;
- animation and physical simulation of the behavior of such objects, in order to interact with their virtual representation.

SAARA is implied in many national and European projects. One of the major activities of SAARA is carried out within the French hadrontherapy project, named ETOILE PROJECT. SAARA seeks to determine with precision the organs displacement (specially the lungs motion) during a beam therapy session, in order to enhance the quality of the treatment.

Determination of the 4D geometry of lungs

In the literature, one can find some works focusing on respiration modeling. Unfortunately, these models do not take into account the anatomical reality. In this framework, we are developing a model to simulate the anatomical functions taking into account the independent actions of ribcage muscles and of diaphragm.

In our approach, lungs are fixed near the trachea, and the inflation is simulated by applying a negative pressure to the lung surface and allowing sliding against pleura to take into account for the lubricating fluid inside the pleural cavity. The negative pressure models the muscle actions (ribcage muscles and diaphragm). A clinical study showed that our model gives predictions in better agreement with clinical data in comparison with results of mechanical model proposed in the literature.

Our current works concern the synchronization between our model and patient's real respiratory movement during the radiotherapy treatment. For this, the movements of the ribcage is to be monitored with the help of the acquisition of the external movements of the ribcage wall, developed by the team. Using continuum mechanics, we control our recently developed inverse kinematics model of the ribcage, which plays a significant role in the pleura outer-surface motion and therefore in the lung motion. The monitoring of the diaphragm is more problematic. The acquisition of another parameter (expired/inspired air volume, or movement of the abdominal wall) should permit the quantification of the diaphragm movement. The transformation of the 4D-lung model into CT scan model, namely the Hounsfield units, are derived from the matter density by applying a calibration function and a convolution process to take into account for the scanner characteristics.

ECSON PROJECT

Invited by the ADSIP, LJMU and Christie hospital, LIRIS members could participate in several ECSON meetings. These reunions permitted a high quality scientific exchanges between several teams gathered together by ECSON consortium. This allowed to plan several new activities, particularly:

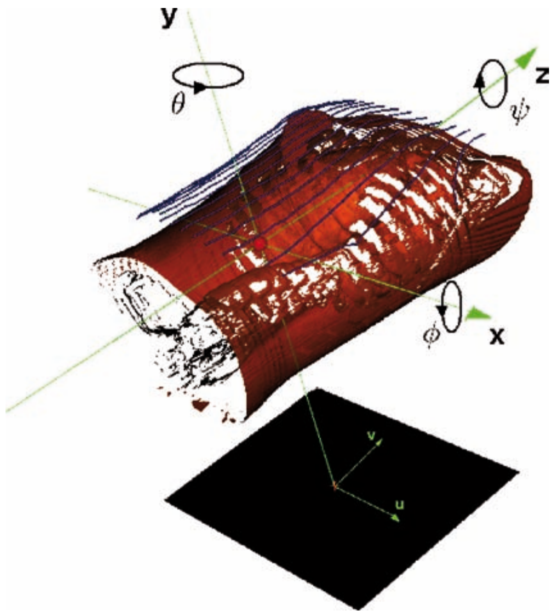
- Collaboration with ADSIP on articulated registration and segmentation,
- Reinforcement of our links with LJMU and Christie on synchronised data acquisition, to pilot our 4D lung biomechanical model.

Otto-von-Guericke University Magdeburg (OVGU) - Germany

The Technical Computer Science team belongs to the Institute for Electronics, Signal Processing and Communication Technology of the Otto-von-Guericke University of Magdeburg (OVGU). The research team is working in the areas of digital image processing, artificial neural networks, fuzzy systems and processor architectures for real-time processing. Its topics of interest span both basic research and applications in medicine, biology, automation and information engineering.

Tumour recognition in 3-D image data has been an important field of biomedical research of the group. Successful research has been done in the field of reconstruction of small parts of nerve cells in 3-D image data and on the field of information coding in nerve cells. Facial expression analysis by stereoscopic cameras has been applied to pain analysis of patients.

In previous projects related to radiotherapy the OVGU team successfully developed methods for processing the images produced in radiotherapy by fuzzy methods and by an associative memory including other data modes. A specially developed photogrammetric optical sensor at OVGU was used for data fusion of the different image modalities (see figure).



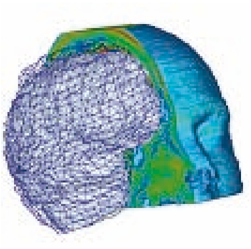
Three-dimensional Fusion of Electronic Portal Image, CT and body surface data

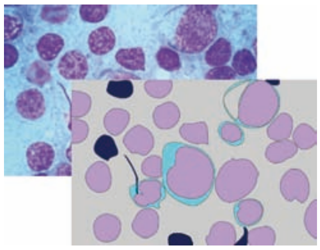
ECSON PROJECT

During the ECSON project OVGU could establish new collaborations with different partners such as UCLAN (Preston) and with ISTI (Pisa).

The research contacts between Liverpool John Moores University, Christie Hospital Manchester and UCBL which had been already on a high level by different previous common European projects could be refreshed.

The ECSON project gave OVGU a brilliant framework to check recent research activities in the field of radiotherapy based oncology and to develop new project ideas together with the European partners.






Signals & Images Lab

Institute of Information Science and Technologies (ISTI)

Italian National Research Council (CNR)

The Institute of Information Science and Technologies (ISTI) is an institute of the Italian National Research Council (CNR) located in Pisa.

The Institute is committed to producing scientific excellence and to playing an active role in technology transfer. The domain of competence covers Information Science, related technologies and a wide range of applications. The activity of the Institute aims at increasing knowledge, developing and testing new ideas and widening the application areas.

ISTI is actively involved in collaborations with the academic world and in cooperative research and development programs, both national and international.

In recognition of the importance of training in today's Information Society, ISTI pays great attention to involving doctoral students and post-doctoral fellows in research activities and participates actively in the doctoral programs of the University of Pisa and other partner universities. ISTI is organized in thematic research labs and technological centres.

The Signals & Images Lab is a Research Laboratory of ISTI working in the fields of signal processing, image understanding and artificial vision.

The Lab was born on the consideration that sensorial information is increasing its importance in both our daily life and the most advanced technological and scientific contexts. In particular, visual and audio information is becoming the most significant part of the global information to be processed, understood and manipulated. Nowadays, more than 35 people actively participate to the Lab, bringing together expertise ranging from computer science to mathematics, from physics to engineering.

The general goal of the Lab is to increase the knowledge in the fields of signal processing, image understanding and artificial vision, in both theoretical and applicative contexts. This is achieved by studying and developing models, computer-based methods and machines for the formation, elaboration, analysis and recognition of images and signals, and by applying these methods and techniques to several sectors of the public and private society having strategic, scientific and technological interests.

The Lab aims at developing its activities dynamically, fully becoming a part of the national and international, academic and industrial network in the field of automated vision. Particular attention is paid to the most advanced research programs and high-level education programs, to the creation of new channels of technical-scientific and industrial cooperation, and possibly to the promotion of spin off initiatives.

ECSON PROJECT

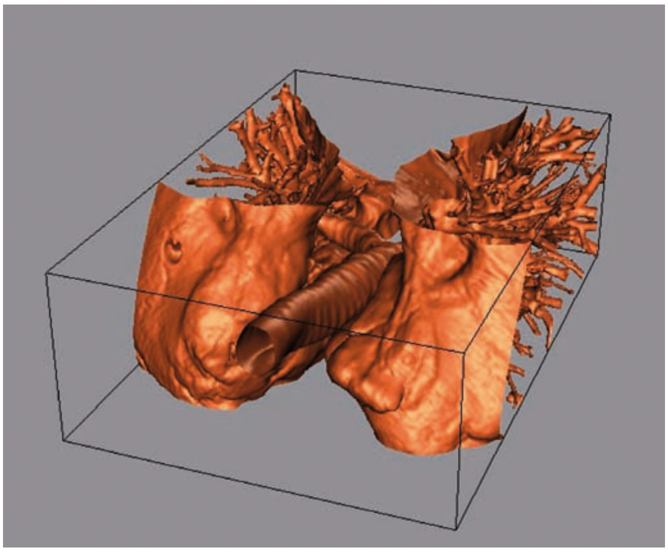
For these reasons, the ECSON project clearly represented a valuable opportunity to pursue the aim of the Lab, by extending the collaboration in the field of medical data processing. Indeed, the ECSON exchange programme and the various meetings enabled the Lab to explore cross-sector synergies across Europe, through the wide and multidisciplinary network of excellence that ECSON partners were able to build. It is likely that this will become a role model for others to follow.

With this respect, the Lab is actively working on several fields that are strongly related to the scopes of ECSON. Indeed the Lab has gained a long experience in the analysis of medical images, for the modelling and reconstruction of 3D anatomical structures and their classification. In particular, working in cardiac applications, several methods for the analysis of deformable structures have been studied, that may be fruitfully extended to the more general contexts considered in ECSON.

In addition, the provision of decision support services for the healthcare is another major area of interest in ECSON. Currently, one of the goals of the Lab is to integrate automatic and semi-automatic image analysis methods in the general process of care, by including –in a holistic approach– other pieces of information regarding the patient (demographics, anamnesis, general clinical parameters…) and introducing advanced inferential and computational reasoning strategies.

Links: **http://www.isti.cnr.it/ThematicAreas/VHPC/si-lab/**

ISTITUTO DI SCIENZA E TECNOLOGIE DELL'INFORMAZIONE "A. FAEDO"



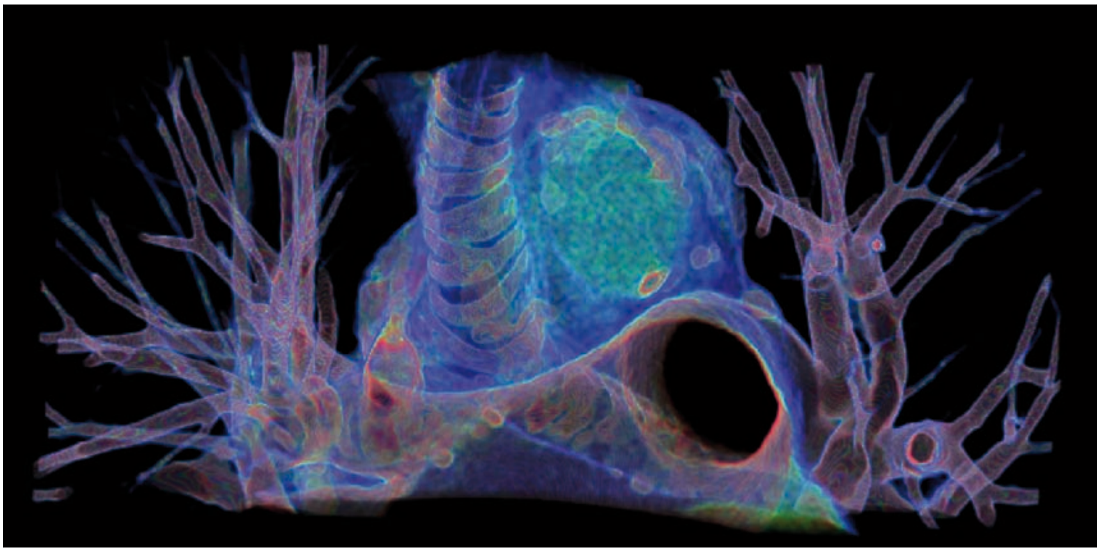
Telemedicine Group, Department of Telecommunications, AGH University of Science and Technology, Kraków, Poland

University

AGH University of Science and Technology, located in Krakow, beautiful old capital of Poland and a leading educational & scientific centre, is one of the biggest Polish technical universities. It consists of 15 faculties and employs about 2,000 faculty members serving nearly 30,000 students within undergraduate, postgraduate and continuing education programmes. Since 1996, the year of its foundation, the AGH-UST Telecommunications Department has taken part in many Polish and European projects (including 4th, 5th, 6th, and 7th Framework Programmes) and with success co-operated with almost all European countries, mainly in the area of new generation internet, optical and wireless networks, data security, content-based data retrieval, multimedia streaming, e-health applications and telemedicine. In turn, the AGH-UST Measurement Department is well-known as a designer of advanced and innovative DSP processor, FPGA and ASIC-based research instrumentation, especially for car traffic control and medical sensing.

Research

Nowadays telemedicine and telepathology systems become more and more important and popular. Our general research objectives are focused on knowledge extraction from different multi-source medical data and its fusion as well as on development of algorithms for computer-assisted navigation systems aimed at precise positioning a patient or medical instruments during medical procedures/interventions. In particular, our activity is concentrated in the following five areas: 1) analysis of ultrasound images (left ventricle wall and intima-media thickness estimation in echograms of the heart and carotid artery), video recordings from traditional bronchoscopy, colonoscopy and gastroscopy (image-based pathology detection), gastrointestinal capsule wireless endoscopy (image compression, enhancement and retrieval, image-based capsule localization) and high-speed video endoscopy (vocal folds movement diagnosis); 2) segmentation, registration and visualization of computed tomography (CT), magnetic resonance (MRI) and endoscopic data in computer-assisted medical navigation and positioning systems, e.g. to support transbronchial needle aspiration biopsy and patient positioning during prostate cancer radiotherapy; 3) virtual bronchoscopy and colonoscopy; 4) speech analysis focused on automatic diagnosis and therapy of handicapped children having pronunciation diseases; 5) designing computer/network systems for medical data management: acquisition, storage, transmission, inspection, browsing, processing and visualization. Our medical partners are Collegium Medicum of the Jagiellonian University in Kraków, Holy Cross Oncology Centre in Kielce and Department of Communication Sciences and Disorders, University of South Carolina, Columbia, USA.



Projects

Last year workers of both departments have been involved in the following Polish projects lying in the field of biomedical engineering:

1) "Development of the Model of Bronchoscopic Navigation System Based on Registration of Endoscopic and Virtual Images (2004-2006),

2) "Computer-Aided Therapy of Children with Disturbed Pronunciation Using Automatic Speech Recognition" (2005-2008),

3) "BRONCHOVID - The Computer System for Bronchoscopy Laboratory Integrating: the Management of the Procedures Recordings, Automatic Image-Based Data Retrieval and Interactive Visualization Using Computed Tomography Data" (2007-2010),

as well as in three international ones (apart from ECSON):

1) European Commission Project "VECTOR: Versatile Endoscopic Capsule for gastrointestinal TumOr Recognition and therapy" (2006-2010),

2) Italian-Polish Bilateral Project "Investigation of hardware features and signal processing requirements for ECG analysis of Myocardial Infarction prediction" (2007-2009),

3) National Institute of Heath Project (USA): "Efficacy of Laryngeal High-Speed Videoendoscopy" (2007-2010).

ECSON PROJECT

Our participation in ECSON was very fruitful. **First**, we had a chance for international exchange of ideas and concepts concerning medical requirements and computational challenges of contemporary cancer radiotherapy. **Second**, due to project activities, our own cross-relations became stronger: detailed co-operation tasks had been defined and a proposal of Polish national project entitled *"Adaptive teleradiotherapy of prostate cancer aiming at minimization of radiation margin"* had been prepared and submitted to the Polish Ministry of Science and High Education (January 2009). **Third**, due to intensive co-operation with ADSIP, significant improvement of our research experience and competence in the area of image processing-based support for cancer radiotherapy has been obtained. At present one Ph.D. thesis on image segmentation and registration is almost finished (A. Skalski: *"3D Segmentation of Medical Data Coming from Computed Tomography and Endoscopic Video Recordings"*, AGH University) and three M.Sc. disertations are in progress (B. Papież *"Registration of Computed Tomography Data in Cancer Radiotherapy"*, A. Szmul "Segmentation of Computed Tomography Data in Cancer Radiotherapy", Michał Wiśniewski *"Atlas Generation for Cancer Radiotherapy"*). **Fourth**, our participation in the ECSON project has resulted also in some interesting joint scientific publications.