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Education & Research in Medical Optronics in France

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Summary

First we present here the main post-graduate courses proposed in France both for physicians and engineers in medical optronics. After we explain which medical domains are concerned by this teaching, essentially computer assisted surgery, telemedicine and functional exploration. Then we show the main research axes in these fields, in which new jobs have to be invented and new educational approaches have to be prepared in order to satisfy the demand coming both from hospitals (mainly referent hospitals) and from industry (essentially medical imaging and instrumentation companies). Finally we will conclude that medical optronics is an important step in an entire chain of acquisition and processing of medical data, capable to create the medical knowledge a surgeon or a physician needs for diagnosis or therapy purposes. Optimizing the teaching of medical optronics needs a complete integration from acquiring to modelling the medical reality. This tendency to give a holistic education in medical imaging and instrumentation is called "Model driven Acquisition" learning.

0. Introduction

Since about 12 years, France has invested a lot in medical optics and photonics, essentially on the optronic side (i.e. in the field resulting from mixing optics and electronics). In this paper, we will present successively the major post-graduate training courses taught at faculties of medicine or at engineering institutions levels in medical optronics. After, we will give some information about the research axes and clinical topics in which we presently need new actors exerting new jobs in medical optronic acquisition and processing: computer assisted surgery, telemedicine and functional exploration. Finally, we will conclude by considering the acquisition process as not isolated, but taking part of a whole programme of observing and modelling the medical reality, serving for example as a template for generating an augmented reality a physician and a surgeon can exploit in order to improve their classical diagnostic or therapeutic procedures.

1. French post-graduate courses in medical optronics

Different institutions of both medical and engineering worlds bring a basic education in classical optics and in electronics for medical applications during the master (1 year) and the PhD (3 years) degrees. The main locations where this teaching is provided are the following :

Paris (Ile de France Region)

In Paris V, Paris VI and ParisVII, there is 2 PhD degree sites, one in Medical Informatics and the second in Bio-Mathematics, involved in optronic acquisition and processing, each PhD education site being able to teach about 20 new students each year. In Paris suburbs, the "Ecole Centrale des Arts & Manufactures" of Chatenay-Malabry has a master degree and a PhD degree in Bio-modelling (about 10 new students each year) and the "Technologic University" of Compiègne (UTC) has master (about 60 new students each year) and PhD degrees in Bio-engineering and Medical Imaging (about 10 new students each year)

Lyons-Grenoble (Rhone-Alpes Region)

In Lyons and Grenoble, 2 PhD degrees (managed by 2 "Ecoles Doctorales d'Ingenierie pour la Sante", i.e. 2 Bio-engineering PhD formations) include inside their courses an education in medical optronics: the 2 corresponding titles are "Bio-medical Engineering" and "Models and Instruments in Medicine & Biology", each "Ecole Doctorale" being able to welcome about 30 new students each year. A new "doctor-engineer" curriculum has been recently proposed at Grenoble, on the topics "Computer Assisted Surgery", "Telemedicine" and "Management of Medical Data Bases"

Besançon (Franche Comte Region)

A new "doctor-engineer" curriculum has been recently proposed at Besançon on the topic "Medical Instrumentation and Medical Informatics", based both on a deep formation in classical optics and optronics and in data base management systems (with a special devotion to microscopic imaging and to micro- nano-technologies), with about 20 new students each year.

The main topics taught in the courses mentionned above are : classical optics, elements of Fourier-Laplace-Gabor-Radon-Meyer transforms, basic electronics, basic image and signal processing methods (3D reconstruction, thin plate Duchon's spline approximation, ray tracing method of visualization, optical flow method of velocity vector field extraction in 4D imaging, 3D registration, signal contrasting & filtering, neural networks approach for enhancement and classification,...), introduction to robotics, introduction to sensor hardware, data fusion techniques.

Two 2-weeks European summer schools (Berder in Brittany for imaging & instrumentation and St Flour in Auvergne for bio-modelling) are completing the French education & research network described above.

2. Computer assisted surgery

The role of optronics in computer assisted surgery (CAS) is multiple :

- to localize the patient surface structures in the operation theater (OT) (by using passive or active infra-red sensors)
- to match the 3D referential corresponding to the deep anatomic structures (acquired by an X detector in the OT) with the 3D referential of the patient surface structures in the OT (Fig. 1 & 2)
- to match the deep and surface 3D referentials of the patient in the OT with the pre-operative (CT-scanner, anatomic or functional NMR, 3D US, PET or SPECT, MEG,..., image devices) referentials
- to guide (e.g. with a laser beam) the surgeon tools.

Figure 1 : coupling the X detector with a 3D-localizer

Figure 2 : hybrid passive/active localizer using 2 CCD cameras

Figure 3 : computer assisted knee surgery (implantation of internal cross ligaments)

Figure 4 : last 3D-matching before action

Figure 5 : navigation using 2 calibrated X-rays

These techniques can be applied to many domains of CAS : knee surgery (implanting internal cross ligaments, Fig. 3), neuro-surgery (putting electrodes in deep structures involved in Parkinson's disease), back surgery (putting screws in vertebrae) and ant & maxillo-facial surgery (putting material in the mandible, Fig. 4). In a near future the own surgeon hand provided by a specific surgical tool (bistoury, biopsy puncture needle, Kocher pinch,...) will be guided at each time in a cone of admissible trajectories : if the surgeon wants to force the CAS system, he can, but a auditory, visual or lingual signal can recall him that he is escaping out the pre-chosen trajectory set of cones going from the skin opening to the final surgical target. To achieve such a hand real-time control, the successive 3D locations of the tool have to be precisely acquired by using an passive or active optical or electro-magnetic marker located on the top and on the bottom of the tool.

3. Optronic sensors in telemedicine and functional exploration

Both telemedicine and functional exploration represent elective fields for optronic sensing. Numerous experiments are documented, among them we can mention two French ones.

3.1. Watching elderly people at home

In order to perform a non-invasive watch of elderly people at home, different solutions have been recently proposed in France :

- use of an smart mattress with 1000 pressure sensors acquiring each 0.4 s an "image" of the patient on his bed, allowing the detection of pathologic exits and of potential skin breaches due to friction. This pressure signal is correlated with an infra-red one (cut of infra-red beams around the bed) and with a video-camera recording with a remote control (for zooming and following up the patient by the nurses of the "Hospital at Home" service located at the referent hospital). It is interesting to notice that for confidentiality reasons, only an automatic alarm triggering resulting from a multi-sensor data fusion will be possible in the future (in particular, the direct video-watching elderly people at home will be suppressed in France, because of its prohibition by the French Commission "Informatics and Freedom")
- use of an smart network of infrared sensors dispatched in the patient flat, each watching an area of about 1 m²; this overlook being in general completed by a pressure and/or video acquisition (the same confidentiality problems occurring than for the bed watch, leading to the same constraint of integrating multi-sensor data and of automatic alarm triggering).

3.2. Performing respiratory functional exploration

In situ quantification of a marker concentration in pulmonary alveolar volumes allows the monitoring of the capillaro-alveolar permeability.

3.2.1. Medical application

Any inflammation of the capillaro-alveolar membrane is a sign of an increase of its permeability which leads to pulmonary oedema. It can be a symptom of adult respiratory distress syndrome or asthma which are major concerns in public health.

In classical clinical exploration, a fluorescent marker (dextran-like) is injected in the patient's blood. The marker diffuses towards pulmonary alveols and remains in the Epithelium Lining Fluid which covers the bronchial walls. A broncho-alveolar washing is then performed by the physician and at regular periods some fluid is extracted for later analysis in a distant laboratory. The typical analysis consists in a fluorescence spectrometry which enables to measure the concentration of dextran contained in the broncho-alveolar fluid.

The project aims to develop a device that would allow direct in situ recording of the dextran concentration. Such a device will provide in a short term the kinetics of the marker diffusion from blood to alveols.

3.2.2. Microsystem based on silicon micromachining and bioreceptors membrane

The basic structure of the Mach-Zehnder microinterferometer has been developed by C. Gorecki et collaborators at LIMMS (joint French/Japanese Laboratory for Integrated Microelectro-Mechanical Systems) [Gorecki et al. 97]. A sensitive window is designed by adding a superstrate layer on one arm of the

interferometer. This superstrate layer interacts with the evanescent part of the wave in such a way that it modifies the effective refractive index of this part of the guide. Any variation of the refractive index in one arm of the interferometer induces interferences such that :

$$\frac{I(\Delta\Phi)}{I_0} = \frac{1}{2} \left[1 + \cos\left(\frac{2\pi}{\lambda} L \Delta n_{eff}\right) \right]$$

with I the intensity, λ the wave length. L represents the length of the sensitive window. A sensitivity of 10^{-4} to 10^{-6} is targeted for detecting changes in the effective refractive index Φ .

In order to detect the molecules of dextran that are used in this application a biomolecular film is deposited onto the sensitive window as shown in the Figure 6. When dextran is fixed by the receptors the effective refractiveness of the sensitive window is changed thus generating interferences [Herve et al. 98].

Figure 6 : Y Junction of the microinterferometer wave guide obtained by

Figure 7 : Microinterferometer (reactive ion etching (RIE) of the SiO_2 upper layer on Si substrate (Gorecki et al. 97)) for in situ measurement of capillaro-alveolar permeability via the measurement of a marker concentration

4. Model driven acquisition

Finally we can say that medical optronics is an important step in an entire chain of acquisition and processing of medical data, capable to create the medical knowledge a surgeon or a physician needs for diagnosis or therapy purposes. Optimizing the teaching of medical optronics needs a complete integration from acquiring to modelling the medical reality. This tendency to give a holistic education in medical imaging and instrumentation is called "Model driven Acquisition" learning. The acquisition process is not isolated, but takes part of a whole programme of observing and modelling the medical reality, serving for example as a template for generating an augmented reality a physician and a surgeon can exploit in order to improve their classical diagnostic or therapeutic procedures. This augmented reality has to be communicated to the surgeon via an auditory, visual or lingual stimulus, forcing them to remain in the limits of a predefined region of surgical action (in which he is allowed to cut organs, to perform biopsy punctures or to pinch vessels). Anatomic and physiologic modelling have then to be used as a bayesian a priori knowledge (coming from anatomic images atlas or from physiologic reference data bases) in order to improve the acquisition, focussing on crucial observables optimizing the diagnosis or the therapy. We give below an extended bibliography on the intersection domain between acquisition and modelling.

5. Conclusion

New jobs are now occurring in medical or in surgical practice : a specific corresponding teaching has to be introduced both in faculties of medicine and in engineering institutes, in order to offer to medical people or to engineers the possibility to cooperate in order to improve the patient care. Teaching optronics at a high level (master or PhD degree) is an essential component of a new multi-disciplinary education based on an excellent knowledge of the acquisition procedures joined to a real ability to model the bio-medical reality : the future of many necessary new medical fields, like telemedicine, computer aided surgery and ambulatory functional exploration is entirely dependent on the capacity we have to create new adapted inter-disciplinary curriculae, especially in optics and electronics.

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