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PRESENT RESULTS AND TRENDS IN MICROWAVE THERMOGRAPHY

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ABSTRACT

We summarize the data obtained on Microwave Thermography, an application of Radiometry devoted to the reception of thermal noise leading to information about the temperature in living tissues. We describe the processes experimented until now and explain their domain of application in biomedical engineering.

Experiments on animals and clinical evaluations are at present being continued. Research is also carried out in the laboratory in order to improve the characteristics of this technique : elaboration of algorithms for thermal Pattern Recognition (or interpretation of the radiometric data) , achievement of a multiprobe scanning microwave thermograph, and the study of the possibilities offered by Correlation microwave Thermography.

INTRODUCTION

Microwave Thermography (M.W.T.) or thermometry is a particular case of radiometry in the measurement of the thermal noise emitted by lossy materials. Recent studies concern applications of M.W.T. in biomedical engineering : due to the relative transparency of the biological tissues in microwaves, it is possible to carry out investigations concerning tissues located at depths of up to several centimeters. Until now, these investigations have shown M.W.T. to be suitable for two categories of applications :

- diagnosis and follow-up : for example for cancer detection, for osteoarticular and inflammatory diseases.
- measurement and monitoring of the temperature during a heating process, for example in hyperthermia for the treatment of cancer.

The research described in this paper has been undertaken by our group for several years. We first summarize the studies made in the laboratory and the applications discovered after the clinical evaluations. Then, we present in which way studies into physical and technological aspects of M.W.T. are being continued.

PREVIOUS TECHNOLOGICAL STUDIES

The first research concerns the definition of processes suited to different situations, the construction of prototypes, experiments on phantoms, measurements on animals and finally, clinical evaluations.

The radiometers are made of low noise, high gain and generally wide band receivers. In order to avoid the emissivity effects at the interface probe-tissue, we first proposed to substitute a zero method to the Dicke radiometer by introduction of a calibrated noise source in the radiometer [1].

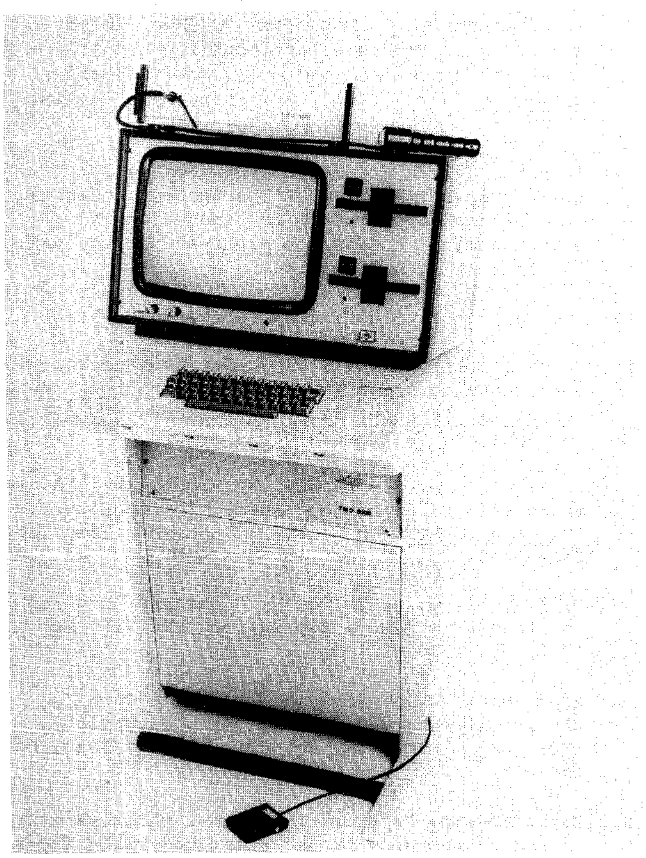

Fig. 1 : System T.M.O. of Microwave Thermography working in S band (ODAM-Bruker).

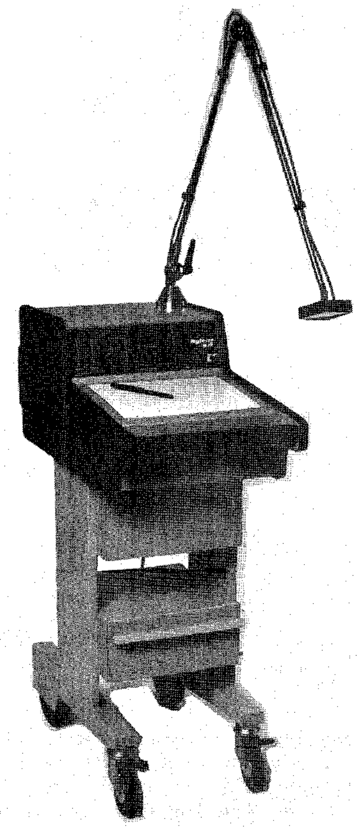

Fig. 2 : System HYLCAR for Hyperthermia treatment, with a non invasive monitoring of temperature by M.W.T. (ODAM-Bruker).

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Later on, a thermal imaging process was proposed [2], which is able to display the noise temperature mapping when the probe is scanned on the surface under investigation.

At the same time, several methods devoted to combining heating by microwaves (or radiofrequencies) and temperature measurement by radiometry were investigated [3] [4]. The purpose of these studies was to arrive at the monitoring of temperature in Hyperthermia.

These studies led to industrial developments by ODAM-Bruker. These microwave thermographs (T.M.O.) are working at S and X band (Fig. 1). The systems Hylcar are able to combine heating by radiofrequencies and microwaves (434 - 915 - 2450 MHz), with M.W.T. (Fig. 2).

STUDIES ON ANIMALS AND CLINICAL EVALUATIONS

Diseases or physiological states, in which a thermal phenomenon occurs at a depth of up to several centimeters can be examined and detected by M.W.T. Material such as bones or fat, which isolate deep seated thermal sources from the skin can be crossed by the thermal radiations, and detected by M.W.T.

Consequently, M.W.T. can be applied to diagnosis, prognosis and the follow up of moderately deep seated tumors (breast, brain, thyroïd). The thermal gradient associated to osteoarticular diseases or ergonomics can also be detected and are studied [5] [6] [7] [8].

In Hyperthermia for the treatment of cancer, the tumoral tissues must be heated to 43° C. The patients are submitted to 15 or 20 sessions. A monitoring of the temperature by thermoprobes implanted in the tumor is painfull and produces inflammatory effects. M.W.T. has been shown to be valid in obtained a non invasive monitoring of the temperature. This has now become a routine procedure in two French hospitals [9].

M.W.T. is also studied for veterinary applications and in physiological studies on animals. For example, the inflammatory effects in deep seated tissues following a localized application of ionizing radiation can be detected by M.W.T. before any external sign is detectable [10].

Physiological studies are being made from observation of the thermal mapping recorded as a function of time.

This is the medical clinics and laboratories involved in these studies :

- Centre Anti-Cancer O. Lambret (Lille) ;
- Clinique de Bourgogne (Lille) ;
- Laboratoire de Thermorégulation - Faculté de Médecine de Lille ;
- Centre de Technologie Biomédicale INSERM (Lille) ;
- Laboratoire de Thermologie - Univ. de Strasbourg ;
- Hospices Civils - Strasbourg ;
- Centre de Médecine Nucléaire - Nancy ;
- Commissariat à l'Energie Atomique (CEA-CNRZ) Jouy en Josas ;
- Laboratoire de Thermographie (Lyon).

PRESENT PHYSICAL AND TECHNOLOGICAL STUDIES

At present, research is being continued in our laboratory in order to improve the performance of M.W.T..

Thermal Pattern Recognition consists of the quantitative interpretation of the radiometric data. We previously defined a method of computation of the radiometric thermal signals based on the Rayleigh Jeans equation and on the reciprocity theorem. The thermal noise power provided by a subvolume of a lossy material to the radiometric probe is proportionnal to its absolute temperature and to a coupling parameter which has the same value if the subvolume is considered as a transmitter (passive process) or a receiver (active process). The total noise power detected by the probe in obtained by a summation achieved from all of the subvolumes coupled to the probe [11] [12]. Consider now a thermal structure such as a tumor umbedded in the tissues ; the radiometric signal recorded when a probe is scanned in front of this thermal structure is called its thermal signature. Algorithms of Thermal Pattern Recognition have been elaborated. They are based on the comparison of experimental and computed thermal signatures. Therefore, we identify the thermal structures which are able to provide the experimental thermal signature. We have shown that a radiometer working at a single frequency can lead to several solutions. However, in many cases, with two radiometers working at two frequencies suitably chosen, we can get a single solution.

In the near future, Thermal Pattern Recognition will be made easier by using a Multiprobe scanning process. Such a system is at present being constructed in our laboratory. It consists of a set of five or six probes connected to the receiver by a multiple switch. With this process, we hope

- to increase the quantity of the radiometric data by a quicker positioning of the probes
- to make the positioning of the probes easier.

However, problems posed by the flexibility of the multiprobe set must still be solved.

In another field, we are working on a new radiometric process which consists of a coherent detection of thermal noise called Correlation Microwave Thermography. In such a system, two probes are connected to a microwave correlator (Fig. 3). The characteristics are quite different to those of classical M.W.T. [13] [14]. The output signal depends only on the thermal noise emitted from the volume of lossy material covered by both the probes. The contribution to the output signal of the subvolumes in this common part can be positive or negative : it depends on their position. With a material at uniform temperature the resulting contribution is zero. Consequently the method seems to be

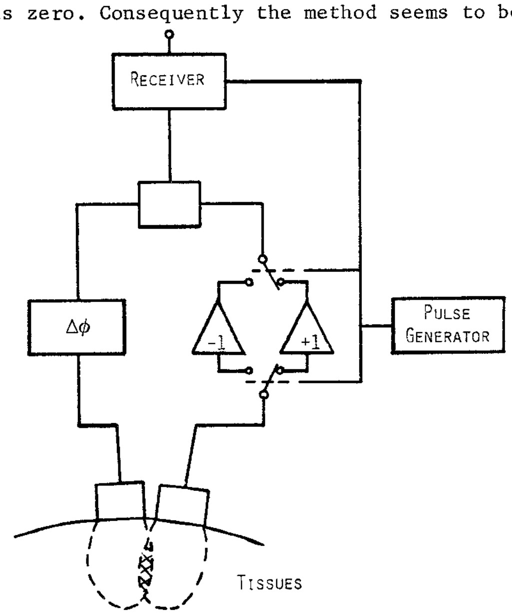

Fig. 3 : The principle of Correlation Microwave Thermography : the output signal depends only on the thermal noise emitted from the dotted volume.

interesting for the detection of steep thermal gradients and small thermal structures. An improvement in the sensitivity of the receiver would further enhance the advantages of this new method which are firstly, a certain flexibility of use due to the possible adjusting of the relative positions of the probes and secondly the possibility of modifying the delay time of the correlator.

The experimental part of this study is carried out using a system built in our laboratory, working in the S band.

CONCLUSION

M.W.T., now interests biomedical engineering [15] [16] [17] and must be considered as a valid new method of non invasive investigation or of temperature control in Hyperthermia. Note that these physical and technological studies indicate possible uses in measuring temperatures for industrial applications too.

ACKNOWLEDGEMENTS

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