Tutorials description

Id	Title	Authors	Abstract
MP	**M**ultispectral **P**yrometry	T. Duvaut (Univ. Reims), N. Horny (Univ. Reims), C. Rodiet (EPF Montpellier), T. Pierre (Univ. Bretagne Sud)	This tutorial deals with the multispectral pyrometry for the temperature and/or emissivity estimation. This is a contactless technique where the radiative emission of the studied surface is recorded by an appropriate sensor. The wavelength bandwidth of the detector should be adapted to the temperature of the surface but also to other parameters, depending on applications. A spectral treatment of the signal offers the possibility to select one or more narrow ranges to estimate the temperature and/or the emissivity. This tutorial is divided in five parts. The first one presents briefly generalities about pyrometry, including its possibilities, limitations and issues. The second part presents the bispectral pyrometry. The third part concerns the detailed presentation of a simple experimental apparatus dedicated to measurement on a constant temperature of surface (600 °C) with different emissivities, including also the pyrometer calibration. The fourth part concerns the optimisation of algorithms used to perform estimations of temperatures with bispectral measurements. Finally, the fifth and last part will present a synthesis of criteria and methods / approaches to minimize errors in temperature measurements obtained by monospectral, bispectral and multipsectral methods.
HP	Thermophysical Characterization by **H**ot **P**lanes	T. Pierre (Univ. Bretagne Sud), P. Le Masson (Univ. Bretagne Sud), Y. Jannot (Univ. Lorraine), A. Kusiak (Univ. Bordeaux)	This tutorial presents the well-known hot-plane technique devoted to the thermal characterization of materials at room temperature. The experiments are transient, the input data and the observable are, respectively, a calibrated heat density, which generate a thermal perturbation in the material, and a local temperature. Both data are recorded at the material front face. The principle of the technique is detailed and the corresponding theoretical models are presented with appropriate assumptions. The experimental part of this tutorial is presented in three parts: first, the calibration with a known material, then the tests and the parameters estimation with materials of different nature, and finally the discussion regarding the limitation of the method, for instance in the case of water saturated porous materials. The theoretical models are developed using the quadrupole formalism, and the parameters estimation is performed according to both determinist (Levenberg-Marquardt) and heuristic fashions (Bayesian inference).
TF	Advanced sensors for **T**emperature and heat **F**lux measurements	F. Lanzetta (Univ. Franche Comté) , B. Garnier (Univ Nantes),	This tutorial is about advanced temperature and heat flux measurement with thermocouples and thermoresistances and can be seen as complementary information to lecture L2. Many various temperature sensors will be presented and also microfabrication of very small thermocouples. Time constants, errors due to heat leakage through the connection wire of the thermocouples will be illustrated with experiments. Some rules will be explained to implement thermocouples in metallic sample in order to realize accurate and sensitive 1D heat flux sensors. Thin film heat flux sensors will also be discussed.

IR	**I**nfra**R**ed Thermography / Material and building	L. Ibos (Univ. Paris Est Créteil), J. Meulemans (Saint Gobain Recherche)	This training session is devoted to the use of infrared thermography for building applications. This session will be divided into two parts. The first part will concern metrological aspects of infrared thermography and more precisely the determination of surface temperature, and its associated uncertainty, using an infrared camera. Uncertainty sources due to the technical characteristics of the camera (measurement noise, non-uniformity, thermal drift) and to the physical properties of opaque surfaces (emissivity, roughness) will be considered. Surfaces of different emissivities will be characterized (spectral emissivity curves will be provided). A particular attention will be paid to the determination of the mean radiant temperature. The work proposed in this first part will be based on theoretical aspects presented in the L4 lecture (“Measurements without contact in heat transfer”). The second part of this training session will be devoted to the study of heat transfers in a building wall using infrared thermography. A reduced scale model of a building wall including thermal irregularities will be used. The work proposed will concern (i) the detection of thermal irregularities such as thermal bridges (or lack of insulation) and (ii) the estimation of the thermo-physical properties of multi-layered walls with an inversion procedure. Practical work will be done using several infrared cameras equipped with cooled detectors or micro-bolometers arrays.
PH	**P**eriodic **H**eating methods for materials thermal characterisation	L. Perez (Univ. Angers)	Periodic heating methods for materials thermal characterization are commonly used when observable signal/noise ratio or sample thermo stability are low. This workshop is intended to illustrate the ways of analysing the sample thermal behaviour in order to estimate thermal properties. The experimental apparatus is based on cheap heating device and temperature measurement system so as to make it adaptable for educational purpose. The thermal modelling is based on complex temperature approach (amplitude and phase lag of temperature evolution). The parameter estimation procedure is developed (sensitivity analysis, errors sources analysis with a particular attention on noise effects, optimal conception of experiment ...). Two estimation strategies (complex temperature space distribution or frequency evolution) are described, illustrated and compared. Additional information on derived methods usable on problems with increased geometrical complexity with both analytical and finite elements modelling is detailed.

MR	**M**odel **R**eduction by modal analysis	Y. Rouizi, F. Joly (Univ. Evry)	The aim of this tutorial is to show the interest of using modal reduction to solve inverse problems. The tutorial is structured in two parts. The first one concerns the construction of the modal reduced model from an already known detailed model (finite elements). Several modal bases will be tested (POD, Dirichlet-Steklov), as well as different reduction techniques (temporal truncation, amalgam). The second part deals with solving an inverse problem by using modal reduced models. During this work, we will show the influence of the order of the reduced model on the estimation results and on the calculation times. An example of an estimation of boundary conditions or thermo-physical parameter characterization will be treated. The different algorithms will be coded by participants using Octave software. https://www.gnu.org/software/octave/
TFB	Identification of **T**ransfer **F**unctions and of **B**oundary conditions	D. Maillet, B. Rémy (Univ. Lorraine)	The objective of this tutorial, composed of two 1h30 sessions, is to conceive a virtual sensor (a combination of physical sensors associated with a mathematical model which allows the estimation, by an inverse technique, of quantities associated to locations where no sensor is present). The tutorial is centered on experiments on a a hollow cast-iron cylinder, with 2 thermocouples embedded in the thickness of its wall, with stimulation by a foil electrical resistance over its inner (front) face. Either the transient temperature or the heat flux, at the front face are looked for. So, the instrumented wall itself becomes the « sensor ». Three inversion methodologies are presented in the tutorial. In its first part, if all the structural parameters of the instrumented wall are known, both quantities sought are estimated by a a regularized least square technique (Tikhonov of zero order), the exact model being analytically available in Laplace domain (method of Thermal Quadrupoles). If it is not the case, the second part of the tutorial requires, in a first step, the identification of the impulse response of each thermocouple (a transmittance or an impedance), which corresponds to a deconvolution problem in a calibration experiment. In its next step, a classical inverse heat conduction problem (IHCP) is solved for retrieving both front face quantities in a second experiment. In a last part, the identification step of the second part is replaced by the estimation of the parameters of a model of ARX structure (AutoRegressive model with eXogenous inputs), for retrieving the above impulse responses in a more parsimonious way. Keywords : inverse heat conduction problem - virtual temperature sensor - deconvolution - thermal impedance - thermal transmittance

HF	**H**eat **F**lux identification	J. L. Gardarein (Aix Marseille Univ.), J. Gaspar (Aix Marseille Univ.), J. L. Battaglia (Univ. Bordeaux)	Objectives : Use experimental measurements (a thermal experiment will be done during the tutorial). Estimate a heat flux with embedded measurement. This tutorial is especially designed to the beginners in inverse heat conduction techniques. In many industrial or research applications, it is whether difficult or impossible to measure the temperature on the area of interest (fire safety, nuclear applications, solar devices…). Therefore, temperature sensors may be quite far from the location where the temperature and the heat flux have to be known. As a consequence, specific inverse methods based on sensors data and an appropriate heat transfer model have to be implemented in order to estimate the seek variables (temperature, heat flux, heat transfer coefficient,…). In this tutorial, we propose to detail the inverse procedures associating deconvolution and regularization method (Tikhonov) starting from a simple experimental setup. After a brief presentation of the experimental context, the first step will be the experimental identification of the transfer function. Then, the inversion procedure will be applied on an experimental signal produced during the tutorial. The numerical codes used will be accessible to the participants. Keywords : Heat Flux Estimation, Embedded temperature measurement, Regularization, Linear problem
BI	**B**ayesian approach for **I**nversion	S. Demeyer (LNE, French Standards Laboratory)	The tutorial will enable participants to apply Bayesian inversion algorithms to estimate thermal properties of walls (thermal resistance, thermal conductivity, heat capacity of unit area) and their associated uncertainty from surface measurements of the wall. The Bayesian inversion relies on the setting of prior distributions on the parameters of interest that are combined with the information gained from the measurements to provide the posterior distributions of the thermal parameters. Participants will experiment various prior settings and tuning parameter values as input parameters of a given Bayesian algorithm and see the effect on the convergence of the Bayesian algorithm and the posterior distributions. The required software is R with R Studio user interface. Key words: Bayesian inversion, uncertainty quantification, prior distribution, posterior distribution, thermal parameters of walls, R software Bayesian inversion, uncertainty quantification, prior distribution, posterior distribution, thermal parameters of walls, R software

TM	**T**hermo**M**echanical inversion	J.G. Bauzin, M.N. Nguyen, N. Laraqi (Univ. Paris Nanterre)	The aim of this tutorial is to present an inverse thermomechanical methodology. By means of an analytical approach, we establish a thermomechanical transfer function between the temperature of a heated surface and the mechanical distortion of a solid at a given abscissa far from the surface. Subsequently, we measure the distortion at discrete time intervals using strain gauge and we apply a deconvolution product to those measurements to identify the temperature of the heated surface. By this way, it is no longer necessary to know the temperature field to solve the thermomechanical problem of our experimental device. We demonstrate that the inversion procedure can be applied successfully even for situations where the measurement signal is affected by noise, through using the Tikhonov regularization method. Lastly, the surface temperature identified from the deformation measurements is compared to a temperature measurement. Keywords: Inverse thermomechanical problem, Analytical thermomechanical resolution, Transfer function, Strain gauge.
KB	Stochastic state-space models and the **K**alman filter – application to **B**uildings	S. Rouchier (Univ. Savoie Mont Blanc)	Due to the ill-posedness of inverse problems, parameter estimates are prone to a possibly large uncertainty, caused by a series of errors and approximations in the experimental and modelling workflow. First and foremost, any model is an approximation of a real system: this model discrepancy may result from missing physics, overlooked input variables, numerical approximations, erroneous hypotheses, etc. Most of the time, the inverse problem of parameter characterisation is formulated supposing an unbiased model. In some fields of study, such as heat transfer in buildings, this hypothesis is exceedingly optimistic. Accounting for modelling approximations is essential for the legitimacy of calibrated models and the interpretability of their parameters. One possible way to do so is to use stochastic state-space models, solved with a Kalman filter, for the prediction of states. This workshop will briefly introduce the theory, and give practical examples, of state-space models and the Kalman filter applied to parameter estimation. The application is heat transfer in buildings. Keywords: stochastic modelling, state-space models, buildings, Kalman filter
IRM	Iterative Regularisation Method for surface heat flux estimation at discrete times	Ph. Le Masson, T. Pierre (Univ. Bretagne Sud).	This tutorial deals with the conjugate gradient method and the Iterative Regularisation Method. The objective of this tutorial is to set an example for an estimation method of a surface heat flux defined as a discrete time function. This work is developed with commercial digital tools: Comsol Multiphysics and Matlab. The three equation systems used for this development (direct problem, variation and adjoint) are defined under comsol Multiphysics, the optimization algorithm under Matlab. The next goal is to make a link between Matlab and Comsol with exchanges of files between the optimisation agorithm and the equation systems. This approach saves development time and controls the estimated quantities.