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Estimation of microwave-assisted drying parameters using adaptive optimization inverse techniques☆

J.L. Pedreño-Molina[a,*], J. Monzó-Cabrera[b], A. Toledo-Moreo[c], D. Sánchez-Hernández[b]

[a]*Departamento de Tecnologías de la Información y las Comunicaciones, Universidad Politécnica de Cartagena, Campus Muralla del Mar, E-30202 Cartagena, Spain*

[b]*Departamento de Teoría de la Señal y Radiocomunicaciones, Universidad Politécnica de Cartagena, Campus Muralla del Mar, E-30202 Cartagena, Spain*

[c]*Departamento de Tecnología Electrónica, Universidad Politécnica de Cartagena, Campus Muralla del Mar, E-30202 Cartagena, Spain*

Abstract

In this work, a parametric adaptive optimization architecture is applied for modelling the direct problem of microwave-assisted drying processes. The proposed architecture, based upon the Levenberg–Marquardt (LM) algorithm, gives a solution for the *inverse problem* in a complex mathematical model. Experimental results with leather samples in an pre-industrial installation have verified the capabilities of the proposed model for the estimation of optimum non-variable and time-dependent parameters, which are difficult to measure in a real drying process, such as internal evaporation, electric field, and heating-up period. In order to verify the reliability of proposed architecture, some well-known parameters, such as specific heat coefficients, are estimated and contrasted. For parameter and functions estimation, temperature at the centre of the material and moisture content are measured and simultaneously considered. Finally, from analysis of obtained results, some conclusions are extracted with reference to improve the knowledge of internal characterization of microwave-assisted drying processes.

Keywords: Inverse problem; Parameter optimization; Microwave-assisted drying; Temperature and moisture contents

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* Corresponding author.
E-mail address: Juan.Pmolina@upct.es (J.L. Pedreño-Molina).

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1. Introduction

The numerical modelling of microwave-assisted drying processes is a complex task that requires the accurate knowledge of several thermo-physical, dielectric, and boundary condition parameters that appear in the mathematical formulation [1,2]. The experimental estimation of such parameters strongly depends on the considered model and, very often, requires specialised instrumentation, not always available for research activities [3]. The identification of model coefficients from experimental temperature and/or mass transfer data, known as an *inverse problem*, is an alternative to the experimental determination of those parameters, but it needs the development of specific mathematical and programming techniques [4]. Adaptive optimization algorithms are capable to find optimal parameters for fitting mathematical models to experimental data, when these models are well-posed and dimensioned. Starting from time-domain analysis of temperature distribution and moisture content, an efficient design of the adaptive algorithm can be able to optimize both fixed and time-dependent parameters involved in drying process. The Levenberg–Marquardt (LM) [5] algorithm has been implemented by other authors for simultaneous parameter estimation applied, for example, to experimental data of temperature and moisture contents [6] or to optimize some parameters of Luikov's model [7] in the construction material-drying processes [8]. On the other hand, optimization algorithms for functions estimation can be found in applications for solving temperature-dependent heat flux in turning tool insert during machining [9], or for specific heat estimation of materials in heat conduction problems [10].

In this work, an architecture based on the LM algorithm has been applied to temperature and moisture content measurements in microwave-assisted leather drying processes. Two parameters (the heating-up period and the initial electric field within the sample) and the time-dependent evaporation function of the model described in [11] have been optimized. Then, the estimation of well-known parameters of leather material samples, such as the dry mass and the phase liquid specific heat, has in turn allowed a validation of the proposed architecture and the mathematical model. Results from several experiments with varying operating conditions are also discussed.

2. Theoretical study

2.1. Heat and mass transfer analysis

The mathematical model employed on the study of microwave-assisted drying of leather has been previously reported and validated in [11] although the most important equations are reproduced here for a better understanding of the parameter estimation procedure. In this case, the differential equations that rule the conversion of electromagnetic energy into heat and mass transfer are provided in Eqs. (1–7). See key to symbols in the nomenclature section.

$$-\rho_s \Delta H_v(X)\frac{\partial X}{\partial t} = \eta(t) 2\pi \cdot f \varepsilon_o \varepsilon'(X) E^2(X) \tag{1}$$

$$E(X) = \frac{Eo}{\sqrt{\varepsilon''(X)}} \tag{2}$$