Available online at www.sciencedirect.com
ScienceDirect
Mathematics and Computers in Simulation 116 (2015) 44–58
MATHEMATICS AND COMPUTERS IN SIMULATION
www.elsevier.com/locate/matcom

Original articles

An artificial neural network approach for modeling the ward atmosphere in a medical unit

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Received 29 July 2014; received in revised form 1 March 2015; accepted 21 April 2015
Available online 6 May 2015

Abstract

Artificial neural networks (ANNs) have been developed, implemented and tested on the basis of a four-year-long experimental data set, with the aim of analyzing the performance and clinical outcome of an existing medical ward, and predicting the effects that possible readjustments and/or interventions on the structure may produce on it. Advantages of the ANN technique over more traditional mathematical models are twofold: on one hand, this approach deals quite naturally with a large number of parameters/variables, and also allows to identify those variables which do not play a crucial role in the system dynamics; on the other hand, the implemented ANN can be more easily used by a staff of non-mathematicians in the unit, as an on-site predictive tool. As such, the ANN model is particularly suitable for the case study. The predictions from the ANN technique are then compared and contrasted with those obtained from a generalized kinetic approach previously proposed and tested by the authors. The comparison on the two case periods shows the ANN predictions to be somewhat closer to the experimental values. However, the mean deviations and the analysis of the statistical coefficients over a span of multiple years suggest the kinetic model to be more reliable in the long run, i.e., its predictions can be considered as acceptable even on periods that are quite far away from the two case periods over which the many parameters of the model had been optimized. The approach under study, referring to paradigms and methods of physical and mathematical models integrated with psychosocial sciences, has good chances of gaining the attention of the scientific community in both areas, and hence of eventually obtaining wider diffusion and generalization.

Keywords: Artificial neural networks; Mathematical modeling; Ward atmosphere; Quality of health care; Complex systems

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http://dx.doi.org/10.1016/j.matcom.2015.04.006

1. Introduction

Over the past decade there has been an increasing interest in mathematical models that describe and analyze complex structures and processes such as interacting systems of human beings. It is not infrequent that mathematical theories that are well-known in some research areas strongly contribute to the creation of new methods and perspectives even in fields remote to those that motivated their introduction. This is the case of the so-called artificial neural networks (ANNs), which in recent years have been applied as a statistical data modeling tool to atmospheric sciences [23,45,1,30], energy systems [28,26,38,16], experimental and clinical medicine [6,43,3,48,31,44,20,19,4,37], medical diagnosis [29,5,7,41], and a huge variety of other settings. An ANN is a mathematical/computational model inspired by the structure and functional aspects of biological neural networks. It consists of an interconnected group of artificial nodes, or neurons, arranged in three or more layers: the first layer consists of input data, and the last layer contains the outputs; in addition, there are one or more hidden layers that process the information and establish the correspondence from the inputs to the outputs (see Fig. 1). The ANN is characterized by the interconnection pattern between different layers of neurons, i.e., mathematically speaking, by the activation functions that convert each neuron's weighted input to its output. The network is an adaptive system that changes its structure based on external or internal information that flows through it during the learning process. In particular, in the so-called supervised learning, one uses a (sufficiently large) set of example pairs (x, y) with n inputs, $x = (x_1, \dots, x_n)$ and p outputs, $y = (y_1, \dots, y_p)$, and the aim is to find the activation function in the allowed class that *matches* the examples. Mathematically, this is essentially often reduced to an optimization problem aiming at minimizing the absolute or averaged squared error between the network's output and the target value, y, over all the example pairs. The network training is achieved through a trial-and-error process, in which the network learns how to reproduce the correct outputs from the given inputs by adjusting the statistical weights on the connections between layers (Feed-forward/Back-propagation method) [15].

Motivation. In Refs. [35,36] the authors proposed a generalized kinetic model to describe the time evolution of a variable related to the quality and/or climate of a medical unit. The work was originally motivated by the analysis of experimental data collected for over 10 years in an in-patient psychiatric unit (located in San Pietro Vernotico, Brindisi—Italy) under the direct responsibility of Dr. A.V. Serio, within the framework of a regional research project for monitoring and improving the quality of the service. The authors conceptualized the medical ward as a semi-closed system having two populations: patients and medical staff. The dynamics of the service, and the mutual relations among the individuals depend strictly on the "quality" that is offered (or that is perceived as being offered) by the service, i.e., on the social climate that is established. The experimental data are both quantitative and qualitative, and include: (i) monitoring a variable called Ward Atmosphere (atmosphere, for brevity), which refers generically to the social climate and is well-known in the specialized medical and psychosocial literature since the 1950s (see [53,50,42,21,47,46,39,40,49,51]); (ii) presence of medical operators and staff; (iii) critical events (elopes, episodes of aggressiveness or violence, accidents); (iv) positive and negative events (visits, social activities, leaves of absence; troublesome admissions, such as for patients on compulsory sanitary treatment or at their first hospitalization); (v) flux data (input/output of patients). The atmosphere, in particular, has been measured 3 times a day since January 2001, according to a color code synthetically described in Table 1.

In order to allow numerical and statistical investigations on the collected data, the color code has been converted into the ordered set of five positive integers $\{2, 4, 6, 8, 10\}$, and hence on an equal-interval (ordinal Likert) scale, with 2 corresponding to *green* and 10 corresponding to *red*. Whether individual Likert items can be considered as interval-level data, or whether they should be considered merely ordered-categorical data is a subject of debate in the mathematical and psychosocial scientific communities. Such items could be regarded only as ordinal data, because, especially when using only five levels, one cannot assume that all pairs of adjacent levels are perceived as equidistant. On the other hand, treating it merely as an ordered set without specifying a distance could imply losing important information. While crucial when trying to model the dynamics of the system with a generalized kinetic approach (see [36]), this issue is much less relevant (if relevant at all) in the proposed ANN approach.

The ultimate goal of any mathematical investigation of the system is to predict, on a short-time scale, the possible outbreak of a crisis (orange/red ward atmosphere), and, on a long-time scale, the effects that specific planned or unplanned readjustments of the structure may produce on it and on patients and staff in terms of stress and satisfaction.

Identifying variables, parameters and events that control the dynamics, and thus being able to propose an effective mathematical model of the ward atmosphere and of its evolution is of the deepest importance from a social and