Chapter 1
Introduction to Neural Networks for Instrumentation, Measurement, and Industrial Applications

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1.1. The scientific and application motivations

Instrumentation and measurement play a relevant role in any industrial applications. Without sensors, transducers, converters, acquisition channels, signal processing, image processing, no measurement system and procedure will exist and, in turn, no industry will actually exist. They are in fact the irreplaceable foundation of any monitoring and automatic control system as well as for any diagnosis and quality assurance.

A deep and wide knowledge about techniques and technologies concerning measurement components and systems becomes more and more necessary to deal with the increasing complexity of nowadays systems: pillars of the modern factories, machinery, and products. This is particularly critical when non-linear complex dynamic behavior is envisioned, when system functionalities, components and interactions are numerous, and when it is difficult to specify completely and accurately the system behavior in a formal way. On this base practitioners can build effective and efficient industrial applications.

In the last decade neural networks have been widely explored as an alternative computational paradigm able to overcome some of the main design problems occurring with the traditional modeling approaches [1-22]. They have been proved effective and suited to specify systems for which an accurate and complete analytical description is difficult to derive or has an unmanageable complexity, while the solution can often be described quite easily by examples. Adaptivity and flexibility as well as system description by examples are of high importance for the theoretical and applied scientific researches. These studies and their applications allow for enhancing the quality of production processes and products both in high-technology industries and in embedded systems for our daily life. Consequently, the impact on the industry competitiveness and the quality of life is high. Besides, they open also new perspective and technological solutions that may increase the application areas and provide new markets and new opportunities of employment.

The experiences performed in the academy as well as in advanced industry largely verified the suitability and -in some cases- the superiority of the neural network approaches. Many practical problems in different industrial, technological, and scientific areas benefit from the extensive use of these technologies to achieve innovative, advanced or better solutions. A number of results concerning the use of neural techniques are known in different applications, encompassing intelligent sensors and acquisition systems, system models, signal processing, image processing, automatic control systems, and diagnosis.

1.2. The scientific and application objective

These results have been presented in many conferences and books, both discussing theoretical aspects and application areas. However, researches and experimental application was usually confined in their own specific theoretical area or application with limited broader perspective through the whole industrial exploitation so as to benefit from possible synergies and analogies about achieved results. And, more important, measurement and metrological issues have not been sufficiently addressed by researchers to assess the solution quality, to allow accurate comparison to traditional methods. Industry needs to rely on solid foundation also for these advanced solutions: this greatly conditions acceptance and use of neural methodologies in the industry.

The 2001 NATO Advanced Study Institute on Neural Networks for Instrumentation, Measurement, and Related Industrial Applications (NIMIA'2001), held in Crema, Italy, on 9-21 October 2001, succeeded in filling the gap in the knowledge of researchers and practitioners, specialized either in industrial areas, or in applications, or in metrological issues, or in neural network methodologies, but without a comprehensive view of the whole set of interdependent issues.

The interdisciplinary view -through theoretical and applied research issues as well as through industrial application issues and requirements- focused on the metrological characterization and prospective of the neural technologies. This was the most relevant and original aspect of NIMIA'2001, never really and in-depth afforded in other meetings, conferences, and academic programs.

The international interest of the scientific and industrial communities in NIMIA’2001 is proved by the technical cooperation of the IEEE Instrumentation and Measurement Society (the worldwide engineering association for instrumentation, measurement, and related industrial applications), as well as the IEEE Neural Network Council, the INNS - International Neural Network Society, and the ENNS - European Neural Network Society (the most re-known and largest international scientific/technological non-profit associations concerned with neural networks). Also the following associations, specialized in scientific or technological areas, gave their technical cooperation: IAPR TC3 - International Association for Pattern Recognition: Technical Committee on Neural Networks & Computational Intelligence, EUREL - Convention of National Societies of Electrical Engineers of Europe, AEI - Italian Association of Electrical and Electronic Engineers: Specialistic Group on Computer Science Technology & Appliances, AIIA - Italian Association for Artificial Intelligence, SIREN - Italian Association for Neural Networks, and UNIMI-DTI - University of Milan: Department of Information Technologies.

This book, authored by the lecturers of NIMIA'2001 and edited by its directors, is one of the immediate follow up of the meeting. The first objective of the book is to consolidate the material presented during the meeting and the results of the discussions with attendees in a comprehensive and hopmogeneous reference. The second goal is to produce a tangible media for wider dissemination of this advanced knowledge and the related achievements:

the aim of the meeting was in fact not limited only to the direct interaction with the attendees, but directed also to bring this knowledge to the attention of a world-wide audience.

1.3. The book organization

Like NIMIA'2001, this book presents the basic issues concerning the neural networks for sensors and measurement systems, for identification in instrumentation and measurement, for instrumentation and measurement dedicated to system and plant control, and for signal and image processing in instrumentation and measurement. The underlying and unifying wire of the presentation is the interdisciplinary and comprehensive point of view of the metrological perspective. Besides, it focus on the use, the benefits, and the problems of neural technologies in instrumentation and measurement for some relevant application areas. This allows for a vertical analysis in the specific industrial area, encompassing different theoretical, technological, and implementation aspects: the specific application areas of instrumentation and measurement based on neural technologies are diagnosis, robotics, laser processing, electrical measurement systems, virtual environments, and medical systems.

Each chapter focuses on a specific topic. Presentation starts from the basic issues, the techniques, the design methodologies, and the application problems. First it tackles the theoretical and practical issues concerning the use of neural networks to enhance quality, characteristics, and performance of the traditional approaches and solutions. Then, it provides an overview of the industrial relevance and impact of the neural techniques by means of a structured presentation of several industrial examples.

The program structure of NIMIA’2001 made it a unique and successful forum for interactive discussion directed to higher dissemination of innovative knowledge, stimulation of interdisciplinary research as well as application, better understanding of the technological opportunities, advancement of the educational consciousness about the relevance of the metrological aspects for applicability to industry, promotion of the practical use of these techniques in the industry, and overall advancement of industry and products. Each and every participant had his own contribution from his specific knowledge to bring to the scientific and practitioner communities for mutual benefit and synergy.

This book aims to extend these benefits to all experts in the neural network areas as well as in metrology and in the industrial applications, for mutual sharing of in-deepth interdisciplinary knowledge and to support further advancements both of the neural disciplines and the industrial application opportunities.

1.4. The book topics

From the NIMIA’2001 experience, this book tackles some of the most relevant areas in the use of neural networks for advanced instrumentation, measurement procedures and related industrial applications.

The first six chapters are dedicated to general issues and methodologies for the use of neural networks in any application area: namely, sensors and measurement systems, system identification, system control, signal processing, and image processing.

The first and basic issue to understand the significance and the usefulness of any quantity observed in a system consists of characterizing that quantity from the metrological point of view. This is the target of Chapter 2. The analysis of sensors, transducers,

acquisition systems, analog-to-digital converters, and measurement procedures is in fact required to identify the accuracy of the measured quantity and its relevance for the subsequent use in the applications.

In Chapter 3, neural networks are shown effectively to enhance quality and performance of sensors and measurement systems. In particular, they are proved appropriate to implement sensor linearization, advanced sensors, high-level sensors, sensor fusion, and self-calibration. Design and implementation of systems including sensors and measurement procedures are discussed by tackling all requirements and constraints in a homogeneous framework, encompassing conventional algorithmic approaches and neural components.

In any application the key issue is modeling: Chapter 4 tackles this issue. To solve an application problem we always need to create a model of the envisioned system and figure out a procedure to identify the solution within such a model. In industrial monitoring and control as well as in environmental monitoring, embedded systems, robotics, automotive, avionics and much many other applications, we need to extract a model of the monitored or controlled equipment, system, or environment in order to generate the appropriate actions. The theoretical issues concerning model identification is discussed, as well as the use of conventional techniques. Intrinsic non-linearities of the neural networks make these model families and their ability of static/dynamic configuration an attractive approach to tackle the identification of complex non-linear systems, possibly with dynamic behavior. Neural models, methodologies and techniques are presented to solve this problem and comparisons with other methods are discussed. Some relevant examples point out benefits and drawbacks of neural modeling, especially in industrial environments.

In industrial applications as well as in many systems for the daily life automatic control is a vital part of the system in order to allows for an autonomous and predictable behavior. Many conventional techniques are available in the literature to solve this problem. However, for some complex non-linear cases and for some dynamic systems the conventional solutions are not efficient, accurate, or manageable, while neural networks were proved superior, especially when it is difficult to extract a complete analytical model of the system or when the statistical models are not accurate enough on the whole operating range. Theoretical aspects of neural tracking, direct and inverse control as well as reinforcement learning are discussed in Chapter 5. Some applications are also presented and evaluated to derive some comparative analysis of costs and benefits of neural control with respect to other conventional approaches.

Signal analysis and processing is a relevant area for different applications. In particular, the noise removal is used to enhance the signal quality, signal function approximation is relevant to analyze and understand signals, feature extraction is fundamental to create high-abstraction sensors, and prediction from static and time data series is attractive to foresee the signal behavior. Theoretical issues and some application examples are presented and analyzed in Chapter 6 with specific concern to chaotic time series processing. Comparisons with conventional solutions are also discussed.

Image processing is an important technological area for many industrial and daily-life applications. Noise removal is fundamental to clean the pictures and improve the quality with respect to the visual sensing units. Feature extraction is used to extract high-level information in order to create and capture new knowledge from raw images. Vision systems are useful to guide mobile robotic systems and as driving aids in automotive applications. Character and pattern recognition are useful in a large number of application areas as automatic approaches to perform repetitive recognition tasks in noisy and variable environments (e.g., banking, optical character recognition). Neural networks are shown effective and accurate tools to deal with the low-level image processing operations as well as with the high-level aspects in Chapter 7.

On the basis of these general technologies and methodologies, some specific application areas are then discussed in detail: namely, diagnosis, robotics, industrial laser processing, electrical and dielectrical applications, virtual environments, and medical applications. These cases have particular relevance from the industrial point of view since they constitute the leading edge for many manufacturing processes and are promising solutions for today and future applications.

System diagnosis is a recent application area that largely benefit from the inference and generalization mechanisms provided by the neural networks. Chapter 8 tackles this application area. A non-intrusive approach based on signal and image processing to detect the presence of end-of-production defects and operating-life faults as well as to classify them is highly beneficial for many industrial applications both to enhance the quality of production processes and products, e.g., in avionics, automotive, mechanics, and electronics. The basic issues of using neural networks to create high-level sensors in this application area are shown and evaluated with respect to conventional approaches.

Robotics has many opportunities to make use of neural networks to tackle some major problems concerning sensing and the related applications like control, signal and image processing, vision, motion planning, and multi-agent coordination. Chapter 9 is dedicated to this area. The neural techniques are well suited for the non-linearity of these tasks as well as the need of adaptation to unknown scenarios. The integrated use of these methods also in conjunction with conventional components was discussed and evaluated. Evolutionary and adaptive solutions will make even more attractive the use of robotic systems in industry and in the daily life (domotics and elder/disabled people assistance), especially whenever the operating environment is partially or largely unknown.

Industrial laser processing is an innovative production process for many application fields. The undoubted superior quality of laser cutting, drilling, and welding with respect to conventional processes makes this technology highly appreciated in high-technology industries (e.g., electronics) as well as in mass production (e.g., mechanical industry, automotive). The problems related to real-time control the laser processing and to quality monitoring are discussed in Chapter 10. The use of neural techniques is presented as a highly innovative solution that outperforms other approaches thanks to intrinsic adaptivity and generalization ability.

Electrical and dielectrical applications are one of the fields in which neural technologies were widely and successfully used since some years. Chapter 11 is dedicated to this topic. Electric signal analysis is important to evaluate the quality and the behavior of power supply and, consequently, to monitor and control power plants and distribution networks. Prediction of power load is another application that benefits from neural prediction ability to foresee the expected power needs and act in advance on power generators and distribution. Signal analysis is an innovative aspect of monitoring, control and diagnosis for electric engines and transformers. Observation of partial discharges in dielectrical materials and systems is relevant to guarantee the correct operation of capacitors and insulators. These aspects are widely discussed and compared with conventional approaches in the chapter.

Virtual environments are one of the most recent areas that are becoming important in the industrial and economic scenario. They can be used for simulated reality, e.g., in telecommunication (e.g., videoconferencing), training on complex systems, complex system design (e.g., or robotic systems), electronic commerce, interactive video, entertainment, and remote medical diagnosis and surgery. Adaptivity and generalization ability of neural networks allow for introducing advanced features in these environments and to cope with non-linear aspects, dynamic variations of the operating conditions, and

evolving environments. The use of neural networks and their benefits are analyzed and evaluated in Chapter 12.

Medical applications had and will have great expansion by using adaptive solutions based on neural networks. In fact it is relatively easy to collect examples for many of these applications, while it is practically impossible to derive a conventional algorithm having the same efficiency and accuracy. Neural networks are able to analyze biomedical signals, e.g., in electrocardiogram, encephalogram, breath monitoring, and neural system. Feature extraction and prediction by neural networks are relevant tools to monitor and foresee human conditions for advanced health care. Neural image analysis can be used for image reconstruction and enhancement. Prosthesis include neural component to provide a more natural behavior; artificial senses (hearing, vision, odor, taste, tact) can be also exploited in robotics and industrial applications. Diagnostic equipment made impressive advancements especially by using signal and image processing for non-intrusive scanning. These are the main cases considered and discussed in Chapter 13.

1.5. The socio-economical implications

Training researchers and practitioners from several theoretical and application areas on neural networks for measurement, instrumentation and related industrial applications is important since these topics have and will have a major role in developing new theoretical background as well as further scientific advancement and implementation of new practical solutions, encompassing -among many others- embedded systems and intelligent manufacturing systems.

Training of researchers and practitioners is an investment for the advancement of science and industry that will be paid back in the near future by the technological advancement in knowledge, production processes, and products. This will allow in fact to maintain, to expand or even to achieve a leading role in the international scenario. From this training will in particular benefit the less favorite economic areas: coming in contact with the leading experts and the most advanced technologies will be useful for the economic and industrial advancement, for enhancing their worldwide competitiveness, and for creating new job opportunities.

NIMIA'2001 and this book aim to highly contribute to the above goals. NIMIA'2001 had high relevance for training researchers and practitioners since leading scientists and practitioners were gathered from around the world. This allowed the attendees to have wide and in-depth scientific and technical discussions with them for a better understanding of innovative topics and sharing of innovative knowledge. The authors and the editors of this book wish that it can be useful to much more people around the world.

The increasing industrial interest and the possibility of successful industrial application of soft computing technologies for advanced products and enhanced production processes provide a great opportunity to highly trained researchers and practitioners to find a job or enhance their position. A better understanding and knowledge about the book topics will result in better opportunities for developing the industry, for expanding the employment, and for enhancing the employment quality and remuneration. The authors and the editors wish that this book will have therefore a great impact on the career of researchers and practitioners, especially of the young ones.

Continuous education and worldwide dissemination are additional issues that need to be considered in order to enhance and expand the benefits provided by higher training in the topics of this book. NIMIA'2001 was the starting point that allowed for coordinating, homogenizing, and consolidating educational efforts on neural technologies for

instrumentation, measurement, and related industrial applications. This book, conference tutorials, e-learning environments, and courses for the industry and in the university will open additional perspectives to researchers and practitioners to stay on the leading edge of science, technology, and applications.

Interactions occurred during NIMIA'2001 and through continuous educational programs derived from this meeting as well as this book have also a relevant social impact. They in fact allowed and will allow for establishing new reciprocal confidence and understanding as well as to know and appreciate new possible partners and to create long lasting friendships and cooperations. All of the above will be useful for positive globalization and link strengthening, as well as to consolidate worldwide relationships and peace through personal friendships, scientific cooperation and industrial joint ventures.

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