Self-organising maps for intelligent process control

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Abstract

This overview presents the performance of the self-organising map for intelligent process control, especially in the fields of electrical and electronic engineering. At the production of integrated circuits the self-organising map can classify, correlate and predict data and by this way it can improve the yield and the quality of the products. At the evolving area of computational intelligence which stands for systems with artificial neural networks, fuzzy systems and evolutionary strategies, the self-organising maps represent an important part for autonomous systems. The outlook demonstrates the importance of the self-organising algorithm for nanoelectronics.

Extended Summary

One of the most important contributions to neural networks comes from Kohonen who introduced the idea of self-organising maps [13, 14]. He verified this idea by an algorithm of which many applications make use up to now. A very important application area of self- organisation maps is process control. In this field many groups are active now [4]. The impact of these activities comes from the group at Dortmund which is specialised on applications in the field of electrical and electronic engineering [7, 34]. This paper reports especially about these applications.

One of the application areas of self-organising maps concerns the production of integrated circuits. In our example the self-organising map successfully analyses the parameters of semiconductor memories which include process data, electrical data and test data [16, 17]. The self-organising map shows unknown correlations between parameters and predict the quality level of the chips. A similar procedure can be applied to the defects of the masks and to the failures detected in the memory chips on the wafer so the self-organising map can improve the yield of the process [27]. Since the results are very good the industry uses the self-organising maps as an additional tool besides classical statistical methods. Furthermore, this method is also applied to processes in chemistry and steel production as a different approach to process modelling [29, 31].

Moreover, the self-organising feature maps can support the design and the optimisation of integrated circuits. In this case, the vectors consist of design parameters, which the designer easily determines, processing parameters which are determined by the manufacturing line, and test parameters which come from simulated and measured circuits. The engineer can design the circuit by looking at the corresponding points from all component maps, and so he can easily predict the effect of changes in certain parameters. By this way he gets a perfect design centring and he can easily guarantee the quality of the circuit. This method is especially effective for the design of analog circuits because they are very complex [5].

An other interesting application area is the monitoring of power devices [18]. During operation the diagnosis system measures the parameters which are fed into the self-organising map. After the classification the system indicates the state of the devices and gives a rough estimation about their life time. The paper gives an example how the bond quality of the power devices is determined. The Kohonen map indicates a high-quality and a low-quality region so the movement of the measured resistance in the Kohonen map distinguishes between devices with a low and high quality. In future this method will be extended to define the save operation area (SOA) which is relevant for the reliability of the devices. This support for the design of power devices will be unique and is only possible by a self-organising map which can handle an N dimensional data space.

The analysis of dynamic processes is demonstrated on power plants, especially on the characteristics of a boiler, since there are many process parameters which should not be regarded in an isolated way but in a holistic way. The holistic method considers the impact of many small deviations of the process variables and the mutual feedback between them. The self-organising map offers such a method and it is an ideal tool for simple visualisation and analysis of the states of the power plant. The additional advantage of the map is that it can record and analyse transient process operations and complete start-up or load-change operations [18].

A new area of the self-organising map will arise from the field of computational intelligence or soft computing which seems to be a new emerging field [11, 25]. This field combines fuzzy systems, neural networks and genetic algorithms. Fuzzy logic is a method for representing information in a way that resembles natural human communication and for manipulating that information similar how humans handle this information. An early complaint about fuzzy systems is that they are based solely on human instincts and unlike neural networks cannot adapt or learn automatically. Adaptive fuzzy systems employ neural networks as learning techniques. The integration of fuzzy and neural techniques is an active area of research of today. It brings together the best features of fuzzy logic and neural networks, providing knowledge based systems that can adapt or be organised according to sampled data.

The feature of neural networks enables the system to learn by itself. It can create new rules and define new membership functions in the fuzzy controller. By this way, however, the system may become very complex and contain contradictory rules. Genetic algorithms offer a method to make the system more efficient by reducing the number of its rules and by adjusting the shape of its membership functions. This process has to optimise between accuracy and complexity of the system.

The first example describes the diagnosis system for electrical motors which contains a self-organising feature map combined with a fuzzy system for analysing the best match positions by user defined rules. Two outputs are generated: the first represents the current state of the process, the second is the forecast for future states. During the start-up phase the self-organising map learns the input patterns that are selected by the expert of the process. It is important to have dates for all interesting states that means of the defect and catastrophic states, too. When the learning results are visualised, the expert separates the map into different areas corresponding to the states of the process. The borders of these areas and the knowledge about these areas are stored in the system as fuzzy membership functions and rules. The principles of fuzzy logic are suitable for this problem, since the areas cannot necessarily be separated exactly. To define limits for the forecast of future states, the movement of the current best match position has to be taken into account. There are two interesting values according to a movement, the velocity and the direction of the movement. A suitable application for this system is the online motor monitoring and the forecast of future states. A coal mining company is using such a diagnosis system in a test phase [11, 24].

In the second example the self-organising map interprets the clusters mapped on it and by this way it roughly defines the membership functions and the rules in a fuzzy controller. By this method a first set of membership functions and rules can autonomously be generated. In the next step they have to be simplified concerning the number of rules, the contradictory rules and the shape and the position of the membership functions. Since this optimisation process is quite complex and not translucent, genetic algorithms offer the adequate tool to do this. As an example the processes of charging various batteries have been characterised by the self-organising map. The batteries show a very complex behaviour because they show the memory effect. After learning and analysing the process data, the areas on the map indicate the membership functions and the rules in a rough way [25, 26, 28].

For many applications the self-organising map can be implemented in software and in adequate processor systems [6, 10]. The speed of self-organisation accelerates if the algorithm is distributed on several processors which are in parallel or if dedicated hardware is added to the general-purpose processor. However for certain real time applications there is the need for implementing the whole algorithm into an integrated system. For a compromise between the efficiency of self-organisation and the level of integration the algorithm may be simplified. The BISOM algorithm uses the Manhattan distance, discrete values for the adaptation function and binary input vectors. A concept of such a simplified algorithm is described and samples of integrated circuits are shown [4, 21, 24].

The importance of the self-organising map regarding a hardware implementation will increase in nanoelectronics, since the map shows an adaptive behaviour, modularity and fault-tolerance [8]. A further important demand is the local operation of the algorithm: The adaptation algorithm of a self-organising map reveals a similarity to partial differential equations. With certain modifications, basically the introduction of a system energy measuring their distance of a given input to the weight vectors the similarity leads to a local adaptation equation. Concerning the type of the differential equations, Schroedinger-like equation as well as the diffusive Haken model have been studied [12, 30].

The characteristics of nanoelectronic devices offer the opportunity to implement neurons with a chaotic behaviour. Introducing such chaotic neurons into a map will allow to make the matrix smaller and to speed up the self-organising process. In addition such maps can be arranged into a hierarchical architecture [15].

Apart from the denotation of self-organisation to characterise an unsupervised learning algorithm, in nanoelectronics, the term self-organisation often stands for creating fine structures without external influences. A well-known example are atoms that organise patterns in a way to form pyramids on a substrate. It follows that self-organisation can be relevant for manufacturing ultra-small structures and for the development of adaptive structures. An example shows how this effect can be used for the personalisation of three-dimensional circuits which will occur at nanoelectronics.

The paper shows that the Kohonen algorithm has a tremendous impact to process control from the gigaelectronic systems as power plants down to nanoelectronics as integrated autonomous systems.

Acknowledgements

These works have been supported by the German Research Foundation (DFG), and are supported in its SFB 386 at the moment. They have also been supported by the EU (ESPRIT BRA) and by the german industries.

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