Hierarchical Approach to Diagnosis using ANNs

Miona Andrejević Stošović and Vančo Litovski

Abstract – Feed-forward artificial neural networks (ANNs) have been applied to defects diagnosis in an electronic circuit, and also a hierarchical approach is introduced in diagnosis procedure. The approach is presented on an example of a mixed-mode circuit that can represent every complex circuit. A voting system is created in order to distinguish which ANN's output is to be accepted as the final diagnostic statement. Three examples illustrate this approach, so validating the effectiveness of this procedure.

I. INTRODUCTION

Whenever we think about why something does not behave as it should, we are starting the process of diagnosis. Diagnosis is therefore a common activity in our everyday lives [1]. Every system is liable to faults or failures. In the most general terms, a fault is every change in a system that prevents it from operating in the proper manner. We define diagnosis as the task of identifying the cause and location of a fault manifested by some observed behaviour. This is often considered to be a two-stage process: first the fact that fault has occurred must be recognized – this is referred to as *fault detection*. Secondly, the nature and location should be determined such that appropriate remedial action may be initiated.

The general structure of a diagnostic system is shown in Fig. 1. Signals $u(t)$ and $y(t)$ are input and output to the system, here denoted as the "Process", respectively. Faults and disturbances (here measurement errors) also influence the system under test but there is no information about the values of these errors. The task of the diagnostic system is to generate a diagnostic statement S, which contains information about fault modes that can explain the behaviour of the Process. Note that the diagnostic system is assumed to be passive i.e. it cannot affect the Process itself.

The number of possible faults in an electronic system may be large and can be located everywhere in the system. In order to diagnose in such conditions we adopted a hierarchical approach where successive diagnostic statements are generated as the level of description of the system is lowered going down towards the fault itself [2], [3]. This allows for smaller sets of faults to be considered at a time at a given hierarchical level. The whole diagnostic system can be divided into smaller parts referred here to as tests. These tests are also diagnostic systems, DS_i ($i = 1, \ldots , n$).

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It is assumed that each of them generates diagnostic statement S_i ($i = 1, \ldots , n$). The purpose of the decision logic (*Voting system*) is then to combine this information in order to form the final diagnostic statement S. Modern automatic test pattern generator may support such concepts [4].
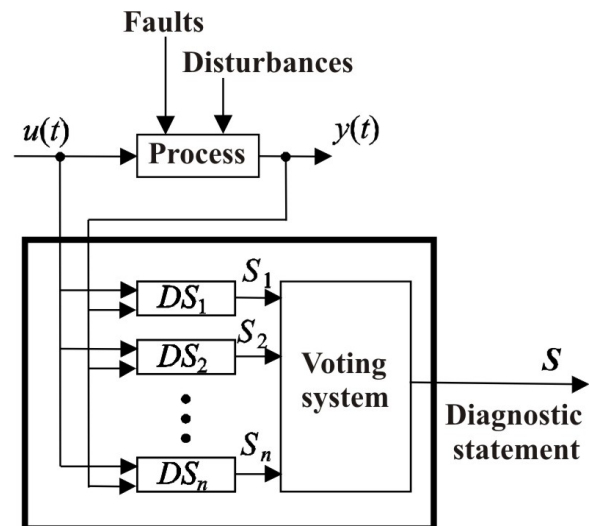

Fig. 1. A general diagnostic system.

II. CONCEPTS OF DIAGNOSIS

Besides the human expert that is performing the diagnosis, one needs tools that will help, and ideally, perform the diagnosis automatically. Such tools are a great challenge to design engineers because, usually, the diagnostic problem is underspecified. In addition, it is a deductive process with one set of data creating, in general, unlimited number of hypotheses among which we try to find a solution. This is why the research community continues to be attracted by this problem [5].

Thanks to the advances in computational intelligence in the last decades new diagnostic paradigms have been applied based on: model-based concepts [1]; production rule based artificial intelligence [6]; ANNs [7]; genetic algorithms [8]; and fuzzy-reasoning [9]; all trying to create an approach that exhibits properties that we might consider to be "intelligent behavior". A comprehensive overview of the complete subject of diagnosis of analog electronic circuit may be found in [10]. Based on that we claim that what we are reporting now is unique and successful attempt to hierarchically diagnose mixed-mode circuit.

In order to get an idea of why and how ANNs are applied to mixed-mode electronic circuit diagnosis, the application of the diagnostic concept (Fig. 1) will be elaborated in some detail first. It involves collaboration of design, test, and field engineers and the mutual distribution of responsibilities throughout the life cycle of an electronic product. We assume that field engineers are expected to react after a functional failure of the system. In order to diagnose such a system they need to be supplied with: testing equipment, a list of specific measurements to be done (including a set of signals and test points), and diagnostic software to process the measurement data. A similar set of data and tools would be given to a test engineer in a production-plant environment in order to evaluate the production yield and create feedback to process engineers when prototyping the circuit.

We believe, however, design engineers are the most familiar with the product and the most qualified and capable to synthesize test and diagnostic signals, and procedures. This means the simulation-before-test (SBT) approach has to be applied to create fault dictionaries containing exhaustive lists of faults and corresponding responses. The fault dictionary is in fact a table representing the mapping from the fault list into a list of faulty (or possibly, fault-free) responses. In that way the diagnostic process becomes a search through the fault dictionary. Alternatively, modern diagnostic techniques using traditional artificial intelligence and reasoning methods typically fall into the simulation after test (SAT) category. This will increase the time spent on diagnosing the system at production time [11]. SBT systems typically require more initial computational costs, but provide faster diagnosis at production time being additional reason why this concept was accepted here.

We claim here that ANNs, being universal approximators [12], are the best way both to capture the mapping, and to search through the dictionary, thereby to perform diagnosis. If large number of faults and reduced number of outputs are to be conceived in the same time, thanks to the resemblance of the fault effects, the search process within the fault dictionary requires highly sophisticated decision making algorithm. We will show in the next how ANNs can perform successfully in most difficult conditions.

III. THE HIERARCHICAL CONCEPT

The practical implementation of the concept in Fig. 1 is depicted in Fig. 2. We assume that we have to diagnose defects in an electronic circuit, which is in most cases a mixed-mode circuit. Having in mind that we deal with complex circuits, with great number of possible defects, it is not practical to consider all defects in the circuit simultaneously. It is common to divide defects in smaller groups, and we will show that in the simplest example, when defects in the circuit are divided into two groups: analog and digital defects. This introduces a hierarchical

approach, when one first has to diagnose to which group of defects our defect belongs, and in the next phase one need to check what kind of defect it really is.
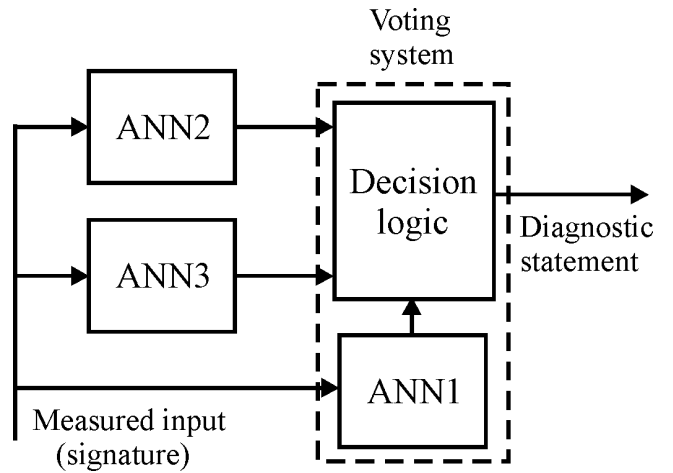

Fig. 2. The ANN based hierarchical diagnostic system.

If we consider Figure 2, we can notice three different artificial neural networks. *ANN1* distinguishes to which group of defects the actual defect belongs, and *ANN2* and *ANN3* need to diagnose defects in two different parts of the circuit (digital and analog, respectively).

Suppose that *ANN2* diagnoses defects in the digital part of the circuit and fault codes are in the range from 0 to 40. *ANN3* diagnoses defects in the analog part of the circuit and, assuming that number of possible digital and analog faults is not the same, we can say that codes are in the range from 0 to 20.

One can notice that we use numbers starting from 0 in both cases in order to denote fault codes. When both *ANN2* and *ANN3* networks work in parallel the user can't distinguish whether the fault code refers to analog or digital defect, if our diagnostic system has only one output, what is in fact the task here. So, we provided *ANN1* in order to help distinguishing if certain defect is digital or analog.

ANN1 gets the same measured signature as an input as *ANN2* and *ANN3* do. Its output code takes values from the set {-1, 0, 1}. Namely, if the defect comes from the digital part, the output code is set to 1, while if it comes from the analog, the output code is set to -1. In the special cases when ambiguity arises, that is when one has the same signature coming from faults belonging to the digital and analog part, we assign 0 to the output of *ANN1*. Ambiguity groups are namely groups of equivalent faults, or aaccording to [13] "an ambiguity group is, essentially, a group of components where, in case of fault, it is not possible to uniquely identify the faulty one".

We will give a few examples now, in order to illustrate the previous explanation.

IV. Application Example

We can assume that the system to be diagnosed has nine outputs, so these outputs are inputs to our diagnostic system, i.e. to all three artificial neural networks (*ANN1*, *ANN2*, *ANN3*), Fig. 2. Output signals are coded as decimal digits, meaning that the diagnostic system is excited with 9 digits. We considered the generation of input signals to our diagnostic system in our previous work [10], [14], [15], [16].

Suppose that we excite our networks with the input signature: { 0 8 2 2 0 2 2 0 8 }. The responses of the three networks are as follows:

ANN1 response: 0.99934
ANN2 response: 30
ANN3 response: -0.0800663.

The *ANN1* response gives us information that the defect is digital, so the decision logic (Fig. 2) decides that we have digital defect (because the *ANN1* output value is approximately 1) and its code is 30 (because the *ANN2* output value is 30). *ANN3* response is ignored.

Next, we suppose that we excite our diagnostic system with the input signature: { 8 0 4 4 1 0 4 2 1 }. The responses of the three networks are as follows:

ANN1 response: -1.00066
ANN2 response: 29.0138
ANN3 response: 4.00001.

We consider now only *ANN3* response because the response of *ANN1* is -1. The conclusion is that we have analog defect (because the *ANN1* output value is approximately -1) and the defect's fault code is 4 (because the *ANN3* output value is 4). *ANN2* response is ignored.

Finally, we suppose that we excite our 3 networks with the input signature: { 1 0 4 1 0 8 2 1 0 }. The responses of the three networks are as follows:

ANN1 response: -0.00172622
ANN2 response: 7.99998
ANN3 response: 11.

We consider now both *ANN2* and *ANN3* responses because the response of *ANN1* is approximately 0, what indicates ambiguity. The conclusion is that we have analog defect with fault code 11, or digital defect coded with 8. We cannot decide which one of them really happened in the circuit because they have exactly the same response, and this is the problem that will not be considered in this paper.

The diagnostic statement obtained at the system level may be associated by another represented at component level what may frequently be the diagnostic task. To do that one needs to perform diagnosis for the subsystems. In the system depicted in Fig. 3, we can notice possible subsystems, *ANN4* and *ANN5*, indicating that every system can have its subsystems. The role of the subsystems may be played by, for example, the digital gates and operational amplifiers.

Identical process of fault dictionary creation and ANN synthesis is expected to be done for every single subsystem in order to perform diagnosis at the lower level.
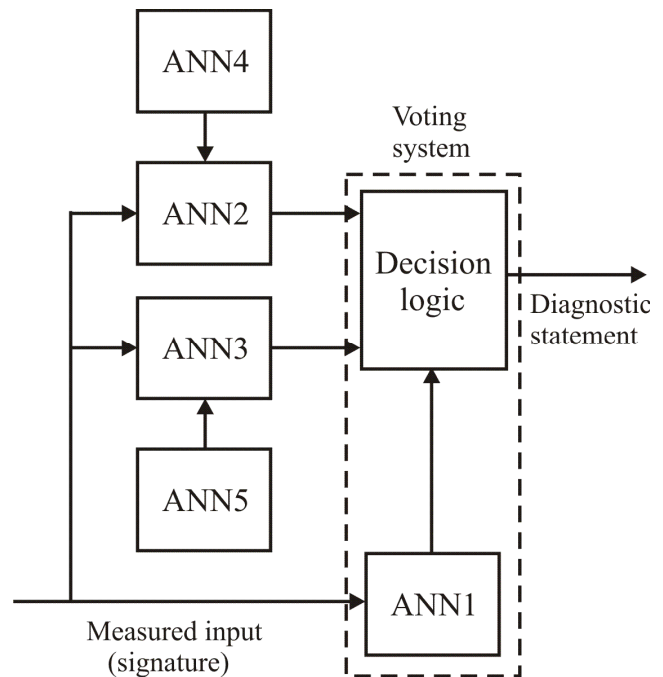

Fig. 3. The ANN based hierarchical diagnostic system with its subsystems

V. Conclusion

In this paper feed-forward artificial neural networks were applied to defects diagnosis in an electronic circuit. While it is not practical to consider all defects in a complex circuit simultaneously, it is common to divide defects in smaller groups. We created a voting system in order to distinguish which ANN's output is to be accepted as the final diagnostic statement. This introduced a hierarchical approach into diagnosis procedure, when one first had to diagnose to which group of defects our defect belonged, and in the next phase one needed to check what kind of defect it really was. Three examples illustrated this approach, and validated the effectiveness of the presented procedure.

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