Diagnostic Reasoning and Reliability Analysis in Sensor Button Electronic System via Petri Nets

Konstantin Dimitrov Dimitrov and Dimitar Iliev Nurkov

Abstract – **The present paper concentrates on the enhancement of a Petri net concept, and especially for its application for diagnostic reasoning and reliability analysis of a Sensor Button Electronic System (SBES). Some specific Petri net-based models of normal and abnormal behavior for the particular functions and structural modules of the SBES are developed and used in diagnostic reasoning and reliability analysis, performed over the electronic devices, (composing the SBES structure).**

Keywords – **Petri nets, reliability evaluation, diagnostic reasoning,**

I. INTRODUCTION.

For resolving diagnostic issues and providing reliability evaluations of electronics systems structures, it becomes really necessary to define what kind of information should be needed and how exactly this information should be organized. Some specific approaches for modeling of the system activities and system states (including also system functions and structural modules) should be developed and applied during the evaluation and the reasoning procedures. One of the prospective methods, that could be developed and applied for the purpose is the Petri Net approach, which has proven to be really valuable for modeling, analysis and on-line monitoring of electronic systems and devices – [5], [6]. Though the Petri Net approach is not a very new concept, in the recent years a significant growth of its application (especially in the areas of process engineering, fault diagnosis, adaptive control, reliability assessment etc.,) could be observed – [2],[3],[4],[7].

The present paper is dedicated to the enhancement of the Petri net concept, i.e., some specific Petri net-based models of normal and abnormal behavior of the particular functions and structural modules of a Sensor Button Electronic System (SBES) are developed and used in diagnostic reasoning and reliability analysis, performed over the electronic devices, (composing the SBES structure).

II. APPLICATION OF PETRI NET-BASED MODELS IN FAULT DIAGNOSIS AND RELIABILITY ANALYSIS

Petri Net-based models, shall be developed for SBES FD, by creating and applying some particular Petri graphs, developed respectively for diagnosis and reliability analysis.

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Petri Nets consists in fact from direct graphs, which are composed of two node types, named "places" and "transitions", connected by direct arcs – [5]. The "places nodes" correspond to system (device) activities and/or partial states, while the "transition nodes" correspond to instantaneous events, i.e., the beginning and/or the completion of system activity. The "marked" (selected) place indicates, what exactly kinds of system activities are in progress, and/or what the states of the corresponding devices are. Respectively, all particular sets of marked places (but only those, that are currently marked), determine the state of the entire SBES. The marking activities in the designed Petri Net proceed, only when the transitions respectively evolve (i.e., corresponding events do occur).

Petri Net-based FD procedures (presented in this study), are developed as a two-stage process, consisting of *fault detection* via observations of discrepancies, generated between the current marking and the actual states of the SBES (1^{-t} stage), and a consecutive *fault isolation* via an off-line simulation-based reasoning (2^{-d} stage).

There exists also an option for development of a one-stage process, consisting of an on-line Petri-net based FD, developed as a supervision, i.e., a real-time simulation of the SPES operation. Such one-stage process could be performed by the Petri-net itself (i.e., through a current marking of an abnormal system states), but the respective FD procedures are not subject to this paper.

III. STRUCTURE OF THE SENSOR BUTTON ELECTRONIC SYSTEM (SBES)

The modular structure of a Sensor Button Electronic System (SBES), which is subject to a two-stage FD process, is presented on Fig. 1.

The SBES consists of a number of different modules, assembled in one package. The particular elements of the modules are: *Sensors* (including analog output and digital output sensors), *Analog to Digital Converter (ADC), Microcontroller (uC), Radio Frequency Unit (RF Unit)* and Power Supply. The new sensor button design will enhance the number of the activities to be recognized (identified) and will be miniaturized in a 3D.

The functionality of the SBES will be completed with the possibility of integration in a *Multi Chip Module (MCM).* The developed system structure provides options for two sensing capabilities – sensors with analog outputs and sensors with digital outputs. Such kind of sensing division, (based on the sensor progress), possesses the tendency of miniaturization of the analog part of the SBES. Such miniaturization shall therefore minimize the power consumption and in the same time shall simplify the structure of the required amplifiers and Analog to Digital Converters.

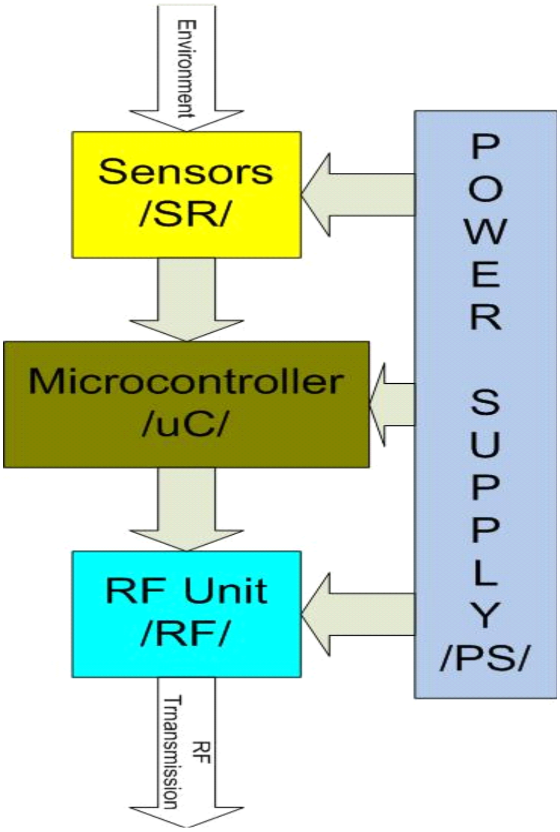

Fig.1. Structure of the SBES.

The newly developed concept, consists in an application of wireless microcontrollers, integrated in the SBES structure. The new structure combines the Radio Frequency (RF) Unit and the microcontroller core, and provides supplementary options for integration of more functions (for the entire SBES) in one single package.

The power unit incorporates a battery and a low voltage boost converter. The total power consumption is calculated on the base of the absolute maximum ratings for all components. The expected maximum current consumption is 50 mA. The power consumption can be reduced during the stage of design and optimization procedures, performed upon the processing algorithms. The application of digital output sensors in the SBES structure, provides a direct feedback from the microcontroller, and prevents the sensors from development of permanent working cycles.

IV. Development of the Petri Net-based Diagnostic Decision Algorithms

The knowledge bases, developed for the purposes of the FD and reliability algorithms included the determination of *normal and abnormal SBES states*, (but only the ones, that could be generated by the SBES functions and modules), as well as the description of some representative *changes of the states* (in fact a particular kind of supervised learning procedures are developed and applied for the purpose). One of the main goals here, was also the creation of explicit models of the SBES *preconditions*, either for *normal and for faulty states*. The necessary knowledge bases are collected from the SBES specifications (available), as well from a ***Failure Mode and Effects Analysis i.e., FMEA,*** developed as reliability analysis procedures of the SBES functions and states – please see [2].

The Petri Net-based modeling structure, designed for the SBES was developed on a basis of a preliminary analysis of SBES functions and structural modules (both of them available), and on a basis of their possible (corresponding) failures, (of course for a provided level of a system description).

The developed FD algorithm is composed of the following diagnostic stages and analytic conclusions:

A. Each *function of the SBES* is associated with particular *places* in the Petri net model, which describe the *normal* and the *abnormal* system *states*.

A.1. The place nodes, representing the normal states provide information (collected from observations and their analysis) for the normal system behavior, while the generated abnormal states for the SBES provide information for the fault *symptoms* (generated during the *FMEA analysis*).

A.2. The transition nodes are associated with the control actions, state changes in the SBES modules, and/or state changes in the SBES functions. Some of the transition nodes can possess capacity for some particular associations with external events (mainly to interactions with the SBES environment).

B. Each *system module from the SBES structure* (and involved in the processing functions) can also be associated with the developed Petri Net model.

B.1. The place nodes correspond (i.e., describe) to the normal and to the faulty states of the SBES modules. These place nodes are usually not directly observable, unless some specific reliability tests are performed over each module, i.e., a determinative reliability tests and control reliability tests can be performed and the results can be linked directly with the place nodes.

B.2. The transition nodes are therefore associated with events, which describe the changes in some representative process variables i.e., whether any particular process variable exceeds a preliminary determined threshold (since a supervised learning is applied in the developed Petri net model).

The resulting Petri net-based model of the SBES functions and structural modules represents in fact a rather complex system structure, composed of connected Petri graphs, which is presented on Fig. 2.

The developed model structure incorporates also the connections, existing between the SBES states and/or activities with the SBES functions and modular states. The existing influences, generated between the SBES states and the SBES activities (and created by the system modules interactions) are also determined and included in the developed Petri net-based FD model.

Various SBES functions, actions and states are therefore developed and presented in the model structure:

- State “OK” for the 4 modules;
- State “Failure” (F) for the 4 modules;
- Action of Maintenance (ACMi);
- Action “Control”;
- Function “Idle” (I)

- Function "Execution" (Ex);

The preconditions are generated only in the cases, when the different equipment modules should maintain the idle regimes (i.e., before the failure occurrence).

The maintenance actions are included in the model structure only for providing options for reversibility in the Petri Net nodes. Thus, a *fault tolerance* of the entire Petri Net, as well as capabilities for *re-initialization* of the model is procured.

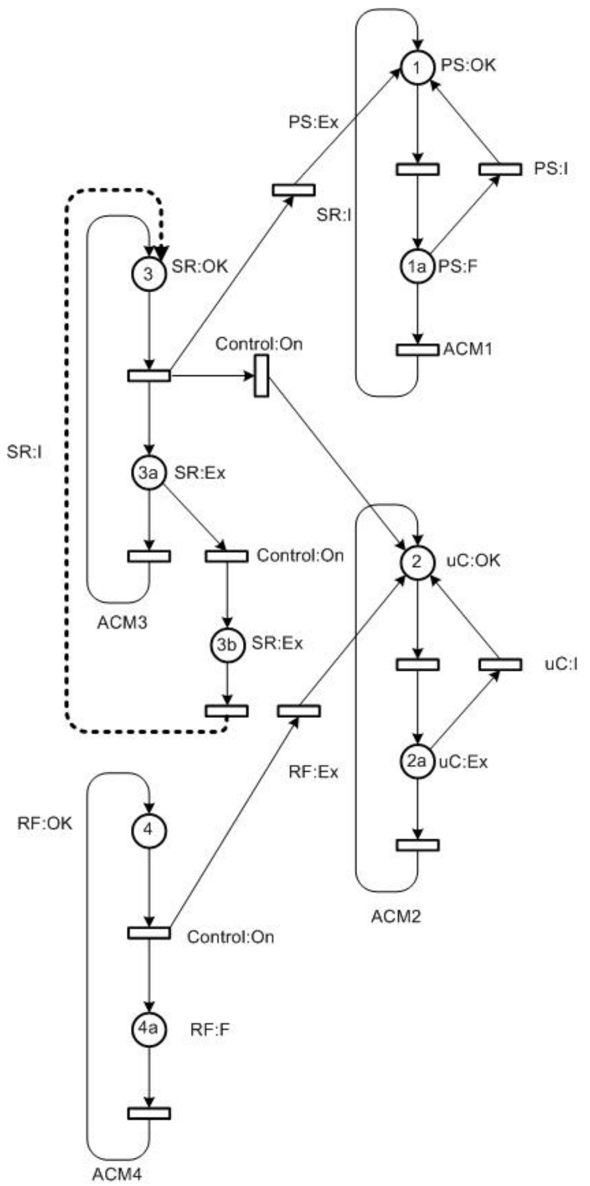

Fig.2. Developed Petri Net-based model of SBES functions and modules.

V. Diagnostic Reasoning in the Fault Isolation Procedures

The developed Petri net model provides also Diagnostic Reasoning (DR) during the Fault Isolation (FI) procedures.

The developed DR algorithm contains the following FI stages and capacities:

A. Fault detection in the SBES (respectively in the Petri Net model) can be performed as follows:

A.1. Through an on-line marking of the SBES *abnormal states*, i.e., a monitoring of the relevant system variables is therefore necessary;

A.2. Through an observation of discrepancies (i.e., inconsistency) between the marking of the model and the actual state of the real system.

B. Fault Isolation event is obvious in A.1.;

C. An off-line Diagnostic Reasoning event is generated in A.2. (Of course, the SBES can remain operational if a fault tolerance is provided).

D. All observable states for the SBES after fault detection are memorized. The SBES states represent mainly fault symptoms, but can also represent some possible observation of normal states.

E. Execution of Fault Isolation (i.e., return to consistency) via adequate setting of fault hypothesis.

E.1. The Petri Net model provides also adequate explanations during the decision generation via analysis of the initial marking and under initial fault hypothesis, which reflects the generated states and abnormal events. If the marked places correspond to the memorized states – then the initial fault hypothesis is correct, i.e., the faults are identified correctly.

E.2. If the Petri Net is not able to provided FI under the initial fault hypothesis – then, another (an alternative) kind of hypothesis must be considered.

The so-developed Petri Net model structure (of the real SBES) possesses some major advantages of the following type:

- All system modules are logically linked to the system functions, so, the functional aspect of the SBS could be enhanced and used for modeling purposes;
- System preconditions, system states and changes in the system states are directly included in the FD reasoning procedures;
- All particular correlations and interactions, existing between the system modules are applied and included during the development of the functional aspects of the Petri Net model.
- The capacities of the Petri Net models provides possibilities for their application in some prospectively developed structures of a complex multi-model intelligent system for FD and reliability estimation.

VI. Conclusions

1. A modular structure of a Sensor Button Electronic System (SBES), which is subject to a two-stage FD process, is developed and applied during the development of FD procedures.
2. An enhanced, Petri Net-based modeling structure, (designed for the this particular SBES) is developed on a basis of a preliminary analysis of SBES functions and structural modules.
3. Diagnostic decision and diagnostic reasoning algorithms, based on the Petri Net model are

developed and applied for FD and FI in the SBES structural modules.

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