Elisabeta Spunei, Ion Piroi, Florina Piroi

Basic Concepts in the Diagnosis of Traffic Safety Installations Using Fuzzy Logic Based Models

The diagnosis of failures in train traffic installations can be done in several ways: direct observations and measurements, software assisted diagnosis using specific software packages, process variable monitoring for electronically centralized installations. This work presents basic concepts for Model Based Diagnosis (MBD) that uses fuzzy logic to analyse the integrity of Centralized Traffic Control Installations (CTC) in train traffic. We define the diagnosis relations to be used and show how to apply them to train traffic security installations. Implementing these concepts into an expert system assists maintenance operators in quick failure diagnosis of the train traffic security installations.

Keywords: *(CTC), Model Based Diagnosis, logic relations, fuzzy logic*

1. Introduction

Railroad Centralized Traffic Control installations are very complex systems that command and control train traffic, being essential in train traffic security. Train stations where the CTC installation is electro-dynamically realised (ED-CTC) have more complex subsystems, each of them, again, having subcomponents that interact with each other. Each subsystem interacts with other subsystems, therefore the safety of the traffic passing an ED-CTC station is ensured when all subsystems function within normal parameter values.

Fig. 1 shows the interconnection block schema for a railway station with CTC and ABS (Automatic Block Signalling) installations.

All subsystems are controlled through the command console, any failure of the one or more subsystem causing an irregular behaviour of the whole system, behaviour which is usually signalled. Diagnosing the system or the subsystem is necessary in order to detect the failing component(s) that are the cause of the faulty behaviour.

Currently, for these types of installations, the failure diagnosis is done by direct observations of the various signals and measurements of equipment states.

The diagnosis time strongly depends on the maintenance staff's detailed knowledge on the whole system and subsystems internals.
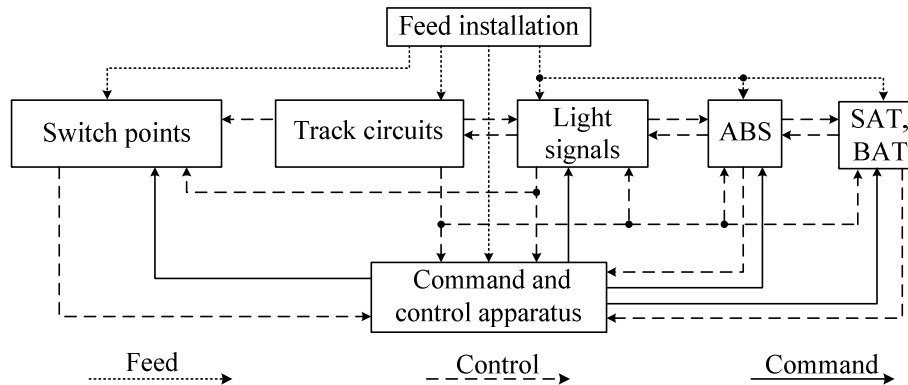

Figure 1. Subsystems interconnection block scheme

This work proposes to develop an expert system (ES) that uses fuzzy logic to diagnose CTC stations. ESs are used also in power electric systems [1].

The expert system will receive information from various subsystem components and will process and compare them with the ES model. The ES output will be a minimal set of causes for the signalled system misbehaviour, corresponding to the signals displayed.

2. Principles of the Model Based Diagnosis

To better understand the basic principles in the model based diagnosis we will use the word *system* to refer to both systems and subsystems.

To use the model based diagnosis it is necessary to completely describe each system component. This step is called *system description, SD* [1,2]. Logical relations that describe how the components work, the links between components, and the workings of the whole system are established. These relations are, in fact, propositional logic sentences that form the *system's propositional logic, SPL*.

A logical consequence of the detailed and correct system description is the correct operation of the system. Any discrepancy between the system's punctual behaviour (pointwise) and its description is caused by a faulty component. Thus the system description is based on the logical propositions that describe the components, their operation and the links between them.

To diagnose a system we must identify all the discrepancies between the system description and its running behaviour. Each discrepancy (or symptom) is determined by a set of concurrent components, CC, which are candidate components for the respective symptom. We can write:

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$$CC \supset CD \qquad (1)$$

An example of a defect, in our case, is the fact that an entry signal cannot be commanded on the 'free' position. The concurrent components of this symptom are: damaged track circuit, damaged track point, faulty power feed installation, line occupied by rolling stock, previously executed movement on the same line, damaged command apparatus. Based on *observations* it is noted that the system failure is caused by the track circuit which does not function properly. In this case the main candidate components are: safeties, transformers, IMVS, BDF, TR relays, the track relay, the filter, the railway tracks, connections, ropes (Fig. 2).
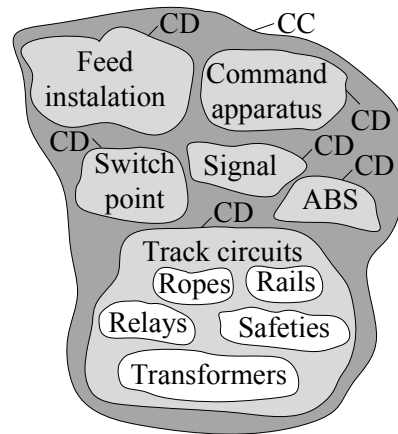

Figure 2. Concurrent and candidate components

In our example, then, we have:

$$CC = \left\{ Switch \quad po\text{int}, Signal, ABS, ...Track \quad circuit \right\}$$

$$CD = \left\{ Transformers, Safeties, Rail \quad track, ..., relay \quad IMVS \right\} \qquad (2)$$

The faults in the track circuit operations are caused by the breakdown of one or more candidate components in the CD set.

We continue with some further basic definitions and relations in the model based diagnosis systems.

The CD's operation state is described by a predicate, AB, which indicates the abnormal operation (faulty state). The normal operation state is given by ¬AB [2].

Definition 1: System description

A functional system, FS, is described by the pair (SD, CD):

$$FS \supset SD \cup CD \qquad (3)$$

where:
- CD is a finite candidate system components set;
- SD is a finite subset of system's propositional logic, SPL.

The system diagnosis, Δ, is applied when the following holds:

$$SD \cup CD \neq FS \qquad (4)$$

Using the AB predicate we can describe the components' functional properties. Suppose we want to express the following sentence: "Normally, the NF1-800 operating voltage is between 8 V and 12 V" [3]. Then, the corresponding relation is:

$$NF1-800(CD) \wedge voltage(CD,u) \wedge$$
$$\neg AB(u) \supset rate(u \geq 8) \wedge rate(u \leq 14) \qquad (5)$$

With the same predicate we can describe the possible effects of the components with the relation:

$$type(CD) \wedge AB(CD) \supset fault_1(CD) \vee fault_2(CD) \vee ... \vee fault_n(CD) \qquad (6)$$

where *type* can be: relays, safeties, transformers, etc.

Definition 2: Observing the system

Observing the system, OBS, is a finite set of first order logic sentences that are used to diagnose the system. Therefore, the functional system can be described by the relation:

$$FS \supset SD \cup CD \cup OBS \qquad (7)$$

These observations belong to the system's propositional logic and their role is to signal the system's faulty behaviour.

Definition 3: System diagnosis

The system diagnosis is a minimal set $\Delta \subseteq CD$, such that:

$$SD \cup OBS \cup \{AB(c)|c \in \Delta\} \cup \{\neg AB(c)|c \in CD - \Delta\} \exists \qquad (8)$$

The diagnosis aims to discover the faulty component that causes the whole system to misbehave. The conditions to apply the diagnosis are:
a) We use the diagnosis for the system (SD, CD, OBS) if:

$$\exists \left(SD \cup OBS \right) \qquad (9)$$

b) $\{\ \}$ is a diagnosis for the (SD, CD, OBS) system if:

$$SD \cup OBS \cup \left\{ \neg AB(c) \middle| c \in CD \right\} \exists \qquad (10)$$

c) $\Delta = \left\{ AB(c_i) \right\}$ is a diagnosis for the (SD, CD, OBS) system if:

$$SD \cup OBS \cup \left\{ \neg AB(c) \middle| c \in CD - \Delta \right\} = AB(c_i) \qquad (11)$$

d) $\Delta \subseteq CD$ is a diagnosis for the (SD, CD, OBS) system if Δ is a minimal set such that:

$$SD \cup OBS \cup \left\{ \neg AB(c) \middle| c \in CD - \Delta \right\} \exists \qquad (12)$$

Definition 4: System's conflicts

A set of conflicts of the (SD, CD, OBS) system is a set $F = \left\{ c_1, c_2, ..., c_n \right\}$, with $F \subseteq CD$, such that:

$$SD \cup OBS \cup \left\{ \neg AB(c_1), \neg AB(c_1), ..., \neg AB(c_1) \right\} \text{ does not exist} \qquad (13)$$

Relation (12) can be redefined using the conflict set terms:
$\Delta \subseteq CD$ is a diagnosis for the (SD, CD, OBS) system if Δ is a minimal set such that $CD - \Delta$ is not a conflict set for (SD, CD, OBS).

Definition 5: The goal set:

Let C be a collection of sets. A goal set for C is a set $H \subseteq \bigcup_{S \in C} S$, such that $H \cap S \neq \left\{ \varnothing \right\}$ for any $S \in C$. O goal set for C is minimal if none of its subsets is a goal set for C.

To compute the diagnosis set we give the following:
Theorem 1:
$\Delta \subseteq CD$ is a diagnosis for system (SD, CD, OBS) if Δ is a minimal goal set for the conflict set collection of the (SD, CD, OBS) system.

3. The Expert System to Diagnose the CTC Installations using the Model Based Diagnosis Method

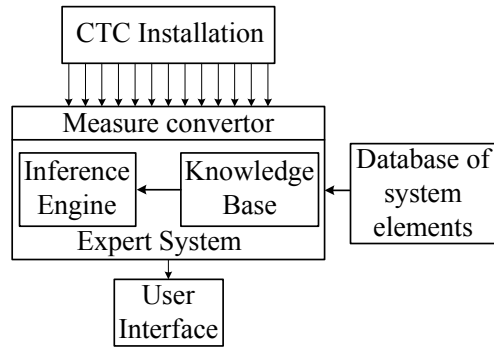The block schema for the connection with the expert system is shown in Fig. 3 [4,5].

Figure 3. The SE interconnection block schema

This diagram contain:
- The CTC installation that is to be monitored at various points and diag-nosed;
- The Expert System that loads into the knowledge base the set of rules for the normal operation state of the installation. The knowledge base is loaded from the database of system elements. These rules are processed by the inference engine that uses fuzzy logic operators [6].
- The user interface where the conflict sets are displayed.

In this work we show an expert system designed to diagnose a CTC type CR4 installation, on a track section with ABS installations.

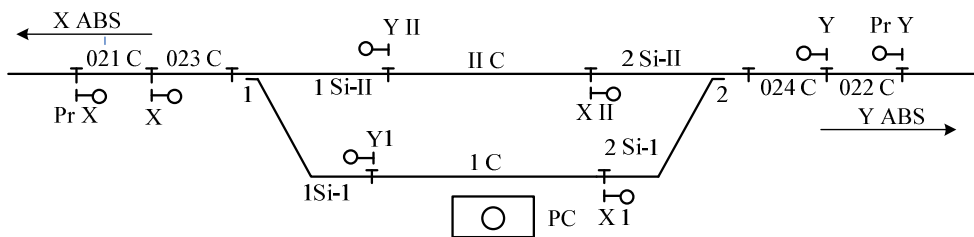Fig. 4 shows the diagram of a railway station with 2 traffic lines.

Figure 4. Railway station diagram for which an expert system is proposed

In this figure we identify the following installations:
- Switch points (no. 1 and no. 2), which allow the train passage from one line to the other;
- Track circuits (023 C, 024 C, 1C, II C) and isolated sections (1 S_i, 2 S_i) which control the 'open' or 'occupied' track states and integrity;

- Light signals (X, X 1, X II, Y, Y 1, Y II) which signal whether the train entry/exit into/out of the railway station is allowed;
- The central post, PC, where the command and control panel is located, as well as the relay room. The command and control apparatus and commands the train traffic and monitors the installation's conflictual state;
- The ABS installation at the X and Y station ends. This installation commands the traffic reversion [7]. This installation contains light signals and track circuits with specific characteristics.

According to this scheme we created the block diagram for the installations that deliver state information to the expert system (Fig. 5).
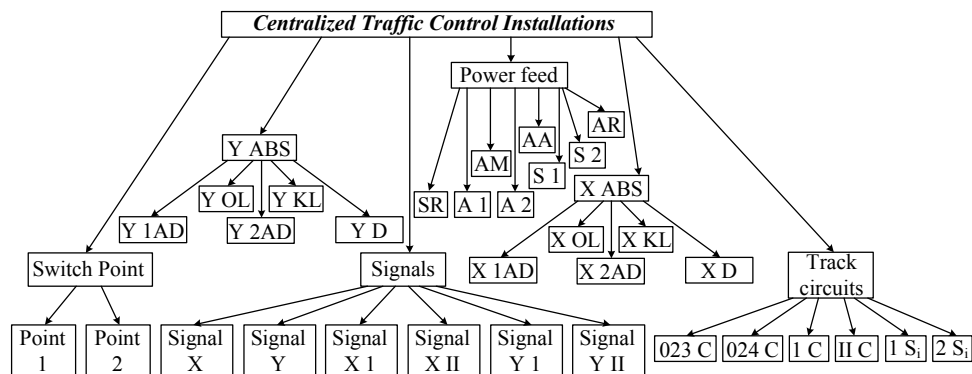

Figure 5. Installation block schema monitored by the proposed Expert System

The DS system description contains:
- The system's topology;
- Locations of the measurement sensors for each mentioned installation;
- Nominal operation parameters for the main installation components;
- Limit parameter values for the operation of the main components in all the mentioned installations;
- The fuzzy rules used to determine the fuzzy indicators.

The CD set, described by $\neg AB(c)$ contains sentences of the form:

-    The correct operation of the switch point (Mac)i is controlled by the point control relays (KM) states, by the point position plus and minus control relays (KMP, KMM) states, where $i = 1, …, M$ and M is the number of point control relays in the station;

-    The correct operation of the signal (Sign)j is controlled by the fire relay FRA (fire red, white) states, by the fire relay FV1G (fire green, yellow 1) state, by

the fire relay FRA2G (fire red, white, yellow 2); where $j = 1, ..., S$ and S is the number of fire relays in the station;

- The correct operation of the (CDC)k track circuits is controlled by the C track relays and S_i isolated section relays, where $k = 1, ..., CC$ where CC is the number of circuit control and section control relays in the station;
- The correct operation of the (ABS)l is controlled by the OL (occupied line) relay, KL (control line) relay, D (direction control) relay, where $l = 1, ..., L$ and L is the number of ABS installations neighbouring the CTC station;
- The correct operation of the power feed installation (ALIM) is controlled by voltage monitoring relays: AM (switch point failure), AA (d.c. power feed), SR (rectifier monitor), etc., where $k = 1, ..., AL$ where AL is the number of voltage monitoring relays in the station.

The union operator, $SD \cup CD$, gives the following sentences:
- The operation of all switch points is correct;
- The operation of all track circuits and section circuits is correct
- The operation of all signals is correct;
- The operation of all ABS installations is correct;
- The electric power feed installation is correct;

The OBS observations set contains sentences of the following form:
- The switch point is positioned A;
- The point states is A;
- The track circuits state is A;
- The signals state is A;
- The ABS installation state is A;
- The electric power feed installation state is A,

where

$$A \in \{optim, favorable, admissible, inadmissible\} \qquad (14)$$

The diagnosis solution using the MBD system is the goal set Δ that contains subsets of the CD set defined like:
- The KMP voltage value is not optimal;
- The FRAG2 relay state is inadmissible, etc.

4. Conclusion

In this work we presented the basic concepts needed to apply the model based diagnosis with an example of concept instantiation for CTC installations. We proposed an expert system applicable to a train station with two traffic lines.

The authors' contributions are:
- Designing the basic block schema for the proposed expert system;

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-   Identifying the elements that need to be monitored and establishing how they should be controlled;
-   Shortly describing the components that are part of the CD set;
-   Shortly describing the DS system and the corresponding operations;
-   Establishing a minimal set of observations.

As future work we plan to further develop and implement this model for the respective installations.

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Addresses:

-   Lect. Dr. Eng. Elisabeta Spunei, "Eftimie Murgu" University of Reşiţa, Piaţa Traian Vuia, no. 1-4, 320085, Reşiţa, e.spunei@uem.ro
-   Prof. Dr. Eng. Ec. Ion Piroi, "Eftimie Murgu" University of Reşiţa, Piaţa Traian Vuia, no. 1-4, 320085, Reşiţa, i.piroi@uem.ro
-   Dr. Techn. Florina Piroi, Institute of Software Technology and Interactive Systems, Vienna University of Technology, Austria, piroi@ifs.tuwien.ac.at