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CONCEPT DEFINITION AND TAXONOMY OF THE ABNORMAL SITUATIONS THAT MAY OCCUR IN CONTROLLED COMPLEX TECHNICAL SYSTEMS

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The problem. We consider a *complex technical system* (CTS) with control executed by a human or a software program. The control process in such system occurs in the discrete time by following some deterministic rules or models that are normally described, say in user manuals [1]. This, however, does not guarantee that the CTS would be necessarily working by following these rules. Any CTS is affected by various multiple unobservable factors. At any time, they can result in unpredictable change of the anticipated deterministic behavior of the system, including its complete failure. Such situations are referred to as *abnormal*; it is important to be able to determine if such situation is going to occur or has occurred.

In some CTS, delay and/or failure in detecting an abnormal situation and delayed or wrong decisions intended to correct them may cause negative or even catastrophic consequences. Things are further complicated by that these decisions should be made in the real time. Such decision making could be based on the deterministic rules that are specified beforehand for each potential abnormal situation (or for a pre-determined subset thereof). This approach is known as situation-based control that is based on mapping the set of situations to the set of control actions [2].

It is apparent that *determining the set of potential abnormal situations* is the key issue in applying this method. This appears to be a complicated problem itself. Some factors contributing to its complexity are, as follows.

- As of today, the concept 'abnormal situation' in the context of managing CTS has no precisely specified meaning. Nor have been developed any generic systems engineering techniques for determining the information that could be used for identifying the set of abnormal situations.
- The input information and the rules determining the CTS behavior, especially in abnormal situations, typically exist in the verbal form that is unsuitable for structuring and building formalized models.
- Too many of potential abnormal situations typically exist. Their total number may be substantial even in rather simple CTS.

These peculiarities give rise to the following three problems.

1. defining the concept of an abnormal situation that may occur in the process of controlling a CTS;
2. developing methods for structuring and formalizing the specifications of CTS; and
3. developing methods for controlling the scale of abnormal situations (situation control models).

The proposed approach. The general approach to solving problems 1 and 2 was proposed in [3, 4]. In what follows, we briefly discuss the definition of an abnormal situation itself. This definition is based on the synthesis and analysis of a structured functional model of control processes in a CTS. A particular case of this concept will be used as a basis for decision making algorithms in abnormal situations.

The concept of abnormal situation is defined on the basis of the following assumptions [5]:

- the set of the states of a CTS is predetermined;
- control decisions are made based on the set of control objectives;
- for each control objective, there exists a subset of states which is referred to as single-objective subset;
- the purpose of the program of control is to accomplish the transition of the system from current state to some state in the intersection of the single-objective subsets and/or maintaining the state of the system in this intersection over given period of time;
- this program of control is based of the model of normal functioning (MNF) of a CTS for given set of the anticipated external factors that would be presumably affecting the system;
- this model is picked from the set of all MNFs; elements of this set differ by the external conditions and the state of the CTS itself;

- the set of MNFs is determined by the decision maker who is responsible for controlling the CTS; this decision maker could be either a human or a software program.

The problem with this approach, however, is that is susceptible to the subjective judgment by the system analysts and/or the decision makers who are responsible for identifying the set of system states, control objectives, determining MNFs, etc. The results of this analysis may be different for different individuals; these findings may also deviate from the real system behavior and may be even inadequate for controlling the system. Therefore, in some situations the control objectives may be unattainable just due to poor design of the control procedure. We believe that such situations, if any, should be considered abnormal.

The above conclusion means that abnormal situations fall in two categories: (1) situations manifesting themselves by the undesirable deviation of the system behavior from what is expected and (2) situations from which it is impossible to achieve the objective state of the controlled system.

In the process of controlling CTS, abnormal situations could be detected if a dedicated online situation classifier is implemented within the system. This classifier should compare the current system state with its anticipated state. (The anticipated states should be determined on each discrete control step.) If current state matches the anticipated state, this situation is classified as normal; otherwise it is classified as abnormal.

All abnormal situations fall in two classes: correctable and uncorrectable.

A *correctable* situation is an abnormal situation for that the system has adequate rules for correcting the system state and possesses sufficient resources for doing so. By 'correcting' it is meant that the abnormal state will change to what is anticipated on the given step of the control process. If there are states other than the anticipated one and for the transition from these states to the objective state would not result in changing the upcoming steps in the control procedure, such states could be also considered as the goal for correcting the abnormal situation.

An *uncorrectable* situation is an abnormal situation for that there are no rules or the system is short of time or other resources for correcting it. Time constraints are determined by the time required for attaining the objective state. All abnormal situations from which the objective state is unattainable belong to this class. In particular, this may happen when it is impossible to determine MNFs, or identify the current and/or the objective state; any of this may make designing the control procedure unfeasible.

The set of correctable abnormal situations should be identified by analyzing the system's MNFs with respect to its other peculiarities. This analysis comprises two steps. The first step is identifying the set of all normal states and/or of its subsystems. These states are specified in terms of the parameters that are relevant to the physical processes taking place in these subsystems and in the system as a whole. Matching the values of these parameters to the physical states of the system makes it possible to provide a meaningful interpretation of the control processes in the CTS. This is typical to the class of the artificial systems that we consider. The second step of analysis is identifying abnormal situations based on the knowledge of the system details. This is only possible if the set of MNFs is well designed which may be accomplished as a result of decomposing the system's processes of normal functioning in the form of well structured formalized models. This decomposition is a standalone problem discussed in [3].

To make it possible to control CTS in abnormal situations, two methods must be developed:

1. a method for identifying the set of potentially correctable abnormal situations (i.e. the situations in which by design the system allows controlling its states) and
2. a method for representing the abnormal situation on the level that allows unambiguous decision making for correcting it.

The principles of the scale control of decision making algorithms in abnormal situations are also based on the possibility to obtain a meaningful interpretation of each potential abnormal situation made in terms of physical processes inherent to CTS. This allows in the early phase of identifying the set of abnormal situations to evaluate the negative impacts and make decision about further detailing such situations and taking them into account in control algorithms.

Therefore, to make the development of the rules for controlling CTS in abnormal situations possible, the following things must be done:

- a set of MNFs for different operational conditions of CTS must be developed;
- potential abnormal situations must be identified for each state in each MNF;

- for each abnormal situation must a set of correction rules be developed or the fact that this situation is uncorrectable must be established (i.e. the set of uncorrectable situations must be identified);
- for each uncorrectable abnormal situation decision making rules must be developed; in particular, these rules may concern:
  - minimizing resource consumption by the system;
  - ensuring safety for the environment;
  - executing unconditional control procedures dedicated for critical abnormal situations (e.g. self-destruction);
  - making predetermined changes to MNFs (adaptation of the models with respect to changes in the system structure or its functioning conditions);
  - initializing identification of new models with respect to changes in the system.

The following general systems considerations have been used for developing models for correcting abnormal situations:

- besides the information used for identifying system states, some additional information about the system behavior may be needed for making an ambiguous choice of corrective action in an abnormal situation;
- detailing the abnormal state to the level sufficient for an unambiguous choice of the corrective action may require several iterations like: *executing rule of correction* $\rightarrow$ *detailing the situation* $\rightarrow \ldots \rightarrow$ *executing rule of correction* $\rightarrow$ *corrective action*.

For similar purposes some additional information about system parameters may be required for decision making in uncorrectable situations. This makes it convenient to categorize system parameters by their use for:

- identifying normal situations;
- detailing abnormal situations for selecting corrective actions;
- detailing uncorrectable abnormal situations for choosing respective actions.

This taxonomy might be useful for determining the set of parameters for remotely monitoring of the system states.

Conclusion. The proposed approach to defining the concept 'abnormal situation' facilitates better understanding of the decision making rules and other peculiarities of control processes in CTS. This also allows more precisely specifying the requirements of the information used in these rules and determine the main directions of future research on the development of structured models of functioning and control of CTS in abnormal situations.

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