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A 2nd Generation Expert System for Checking and Diagnosing AXAF's Electric Power System

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Introduction.

AXAF - Advanced X-ray Astrophysics Facility - is a third NASA's great space observatory (HST launched in 1990 and GRO in 1991). Each of these observatories is intended to cover different part of the electromagnetic spectrum (X-rays for AXAF) and to provide high resolution (undistorted by the earth's atmosphere) images of celestial sources in our universe. AXAF is expected to be launched on an unmanned mission in second part of 1997. It will assume a high altitude, elliptical earth orbit, where it is expected to stay for at least 5 years.

Operation of AXAF is projected to require just below 1800W of peak power. To support this requirement AXAF's electric power system (EPS) will consists of a two wing six panel solar array containing 28,080 solar cells to generate power, three NiH_2 30 Ah batteries each with 22 cells to store energy, a 22-35V bus to distribute power, and associated control electronics. The solar array will supply the spacecraft power and charge the batteries during sunlight period of the orbit. During the eclipse periods, the spacecraft will draw its power from the batteries.

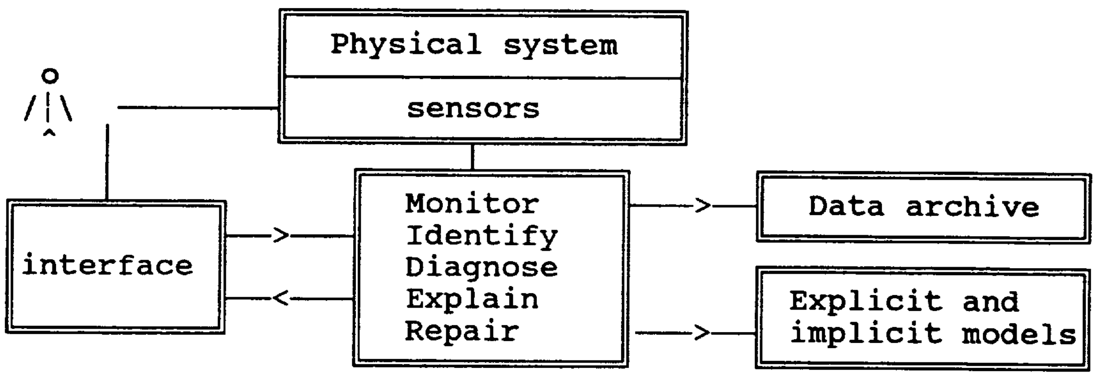
While the spacecraft is in orbit, the EPS performance is monitored via sensors measuring voltages, currents, pressures, and temperatures. The sensor data, are sent from the spacecraft to the ground station as telemetry and analyzed on arrival. When telemetry indicates possible EPS malfunctions, their causes must be dealt with immediately.

Monitoring, diagnosis and maintenance of such EPS is an arduous task which requires expertise and constant attention of the ground personnel. To help the ground crew in this task, much of it should be automated and delegated to an expert (knowledge-based) systems, which draws engineer's attention to possible malfunctions and allows him to review the telemetry to determine the source of the trouble, diagnose the suspected fault and to propose a corrective action [Bykat 1990; Bykat 1991].

Design of ESCAPADE.

First generation expert systems are based on the production systems approach. These systems are built on assumptions such as: a) domain knowledge is available and can be represented as a set of rules, b) domain knowledge is circumscribed, static, and monotonic, c) expert decision making can be emulated by a logical inference mechanism. For applications which support such assumptions, these systems perform well, but when some of the assumptions are violated they will fail, sooner or later.

AXAF's power system is still in design stage. As soon as it is firmed up, EPS test bed will be built and used to acquire the knowledge and expertise needed for managing AXAF's EPS. This scenario violates a number of the above mentioned assumptions. In particular, expertise is almost not available, knowledge is not static, and possibly non-monotonic. To cope with these problems, ESCAPADE' architecture (Figure 1) is based on that of a multi-level (2nd generation) expert system which in addition to the implicit (heuristic) model incorporates an explicit causal model of EPS paired with model-based reasoning.



ESCAPADE deals with the monitor/diagnose/repair cycle. The purpose of monitoring is to detect and describe divergence of incoming observations from expected observations. The expected observations will be elicited from a model of the correct behavior of the device components. The purpose of diagnostic module is to identify components which are responsible for that divergence. Thus, given malfunction symptoms, it uses device's structure, to identify, describe, and localize all of the manifested faults. The diagnosis is then confirmed by generating explanations which verify that the proposed diagnosis is consistent with the observed symptoms. To achieve its goals, the diagnostic module requires access to the device model which in addition to components behavior, should describe the causal and structural relationships governing the device's performance. Finally, the repair module, given the set of faults and faulty components, produces a description of procedures for repairing the device so as to assure that the symptoms identified by the monitor module, no longer manifest themselves in the subsequent data. Here again an access to the device's model is necessary. However, this time, repair knowledge such as structural descriptions and relationships is required.

In first generation expert systems the device model is present in the heuristic rules in a highly compiled ("expert digested") form. This implicit model is static and incomplete making such systems brittle. That is, while coping well with anticipated events, they breakdown when unanticipated events/faults occur. To counter, the heuristic rules of ESCAPADE will be complemented with an explicit model of the device. The model will present structural and causal relationships governing the design and behavior principles of the physical device.

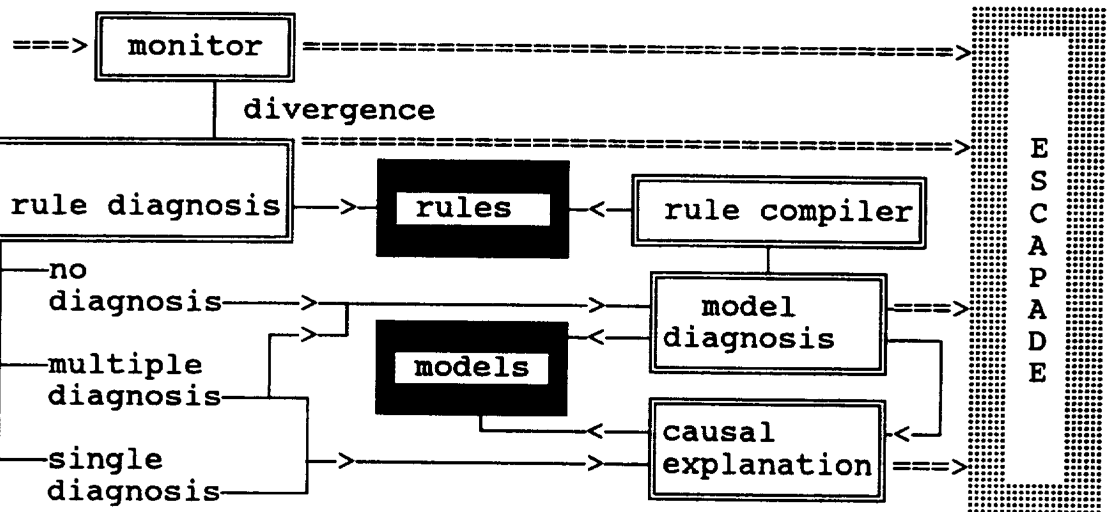
The explicit domain model will be supported by model-based reasoning and will be used to a) reduce the brittleness of the system by performing explicit model-based diagnosis when faced with unanticipated events, b) improve explanation capability by offering explanations based on causal model's description (structure, behavior...) of the device, c) provide a rule learning capability through compiling model-based inferences into new heuristic rules. The components' correct behavior model supports constraint suspension method [Davis & Hamscher 1988] for model-based diagnosis. The rule compiler can be used to offer a methodical coverage of model's search space with heuristic rules (systematic enumeration of the knowledge).

ESCAPADE: reasoning strategy

The ESCAPADE's integrated knowledge base consisting of heuristic rules and an explicit model of the device support a two-level diagnostic reasoning strategy. The adopted strategy is based on the cognitive process of a human (maintenance) expert in which past experience is used first to identify (or to focus upon) possible reasons for observed data divergence, followed by discrimination of hypotheses based on the knowledge of device's operational principles, structural relationships, etc.

Using this cognitive process as a paradigm, ESCAPADE's diagnostic strategy starts with heuristic reasoning on empirical associations of observed data about the system to generate initial hypotheses. If the heuristic reasoning results with no hypothesis, the explicit model is used for qualitative reasoning to explain the divergence. Multiple hypotheses may be dealt with using quantitative analysis to provide the final hypothesis. This strategy is further explained in Figure 2.

This strategy requires construction of an integrated model composed of structural information, functional information, and empirical associations. This knowledge will be represented via rules and frames. Rule compiler uses model-based inference chain of accepted hypotheses to formulate new rules, and to add new rules to the heuristic rule base.



Summary.

ESCAPADE is a knowledge-based system capable of supervising and managing operation of the AXAF's EPS in (semi)autonomous mode. Its main functions are to monitor AXAF's EPS telemetry and identify malfunction manifestations, diagnose suspected malfunctions and explain/verify its causes, and specify a repair procedure. The knowledge base of ESCAPADE will consist of causal models of the electric power system, human expert's empirical operational knowledge, and rules derived from the system's inference chains. (It should be possible and interesting to use ESCAPADE's explicit model to "verify" expert's rules through the model, and to generate rules from the model only.)

ESCAPADE is expected to offer a number of advantages including a) efficient diagnosis due to multi-level reasoning, b) effective explanation due to ability provide judgmental explanations (via heuristic rules) and ability to provide causal explanations (via functional model, structural model, logical model), c) dynamic rule learning through compilation of deep (model-based) inference chains into shallow (heuristic) rules, d) dynamic model adaptation to incorporate environment induced changes in modelled device within the explicit model.

References.

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