Detecting Failures in Space Solar Power Systems with Pattern Recognition

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Abstract
This poster covers work relating to the use of expert systems and pattern recognition to attempt to identify, detect and prospectively stop patterns of activity that could potentially lead to failure of a space solar power (SSP) system. A database-based expert system has been presented to identify patterns, which can be used to determine whether a power beam could hit a unintended target and potentially cause a calamity. This has been implemented via a facts-rule network via which supplied and collected facts and a rule set is used to determine whether the system is operating correctly (from a holistic perspective). The facts-rule network can also be used to determine actions to take to determine the nature of a problem that has occurred.

Facts and Data
Multiple facts have been identified based on the assessment of what types of data would be useful and are available for the satellite. At the most basic, a Boolean value is used to store the beam state (i.e., whether the beam on), whether it is hitting the target and whether any devices used to move the beam currently activated, and what the spacecraft’s current velocity is. More specific raw data points (such as the displacement, allowing some margin for error on the ground for the beam to vary with causing damage), velocity and acceleration (for both the X and Y axis on the ground). These facts have been used to create a rule network that implements safety logic, based on the data that is currently available or easily obtained.

Rules and Logic
Since the beam should appear motionless on the ground and the satellite is up in geostationary orbit, any significant movement could cause the beam on the satellite to depart from its target. So the rule network was developed to carefully monitor the beam’s location as well as factors that could impact targeting and the actual location hit. The rules were designed to identify system failures, malicious users and other prospective problem factors.

Once a problem is identified, it needs to be responded to and located. Depending on the magnitude of this problem, the first step in response may be to disable the power transmission. Whether the beam is disabled or not, the system must locate the source of the problem and determine whether response can be performed onboard or if user intervention is required. The expert system can be utilized to assess prospective problem symptoms, identify diagnostic tests to perform and, prospectively, make a problem determination and a set of rectification recommendations.

Use of Pattern Recognition
Pattern recognition will be used to ascertain what types of errors (and other factors) lead to what specific problems. This allows the system to learn and adapt over time from its operating history. If the system detects a malfunction-associated condition (e.g., the same initial errors as caused a problem previously) it can respond to prevent the issue or mitigate its impact.

The pattern recognition techniques utilized are based on and can be used to augment the expert system rule-fact network.

Conclusion
The idea behind the SSP system is that is can provide continuous clean electricity to the ground. However, critical to user acceptance of this is ensuring that accidents from the beam deviating from its intended target don’t occur. The system discussed herein lays the groundwork for creating a robust and hardware-specific expert system for SSP.

The system is limited by the lack of hardware information which is necessary to make a more robust rule-fact network. Additionally, the lack of a reference system (and operating system) to test the software with also poses restrictions on the work that can be done.

In the future, work on the security assurance system will focus on expanding it to support initial demonstration (e.g., [5]) and production spacecraft. The system will need to be refined based on actual experiences as well as the problems encountered. The expert systems approach (of allowing easy addition of new knowledge) is well suited to this challenge.

References

Tools and Implementation
This project is working to develop two components of an expert system based on a SQL database (used to store the facts and the rules). In an expert system facts are used to determine (by virtue of what rules preconditions are met) what rules to run. Facts can have various data types such as a Boolean and integer values. For example, Boolean values could be used to indicate whether the power transfer beam is activated and whether it is being received by its target.

The expert system approach allows system developers to create and refine their own logic and to collect data to allow detection of problems ranging from system misconfiguration to an attack by a malicious user who attempts to point the beam in an unwanted spot. The system can trigger response actions such as suspending power transfer or alerting human operators.

Background
Multiple advantages exist to using SSP, versus the use of ground solar panels. For example, electricity can be available more reliably, because the system is robust with regards to cloud cover and can operate at night time [1]. The effect of the atmosphere on the sun light is removed and power needs can be normalized across multiple users, facilitating meeting users’ peak needs without having to build numerous systems to supply a level of power that is only needed irregularly. The energy is beamed down to Earth via microwaves or laser beams for use [2, 3]. Despite being introduced in 1968 [4], progress has been limited. Low-earth small satellite testing has been proposed [5] to advance the technology and test relevant control systems [6].

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