A DYNAMIC SYSTEM MODEL VALIDATION SCHEME WITH FUZZY LOGIC TECHNIQUES

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ABSTRACT

With the collaboration effort, a computer simulation model [1] has been developed for the Resonance Control Cooling System (RCCS) at Spallation Neutron Source (SNS). The primary purpose of this dynamic model is to investigate the controllability of the existing mechanical system under varies RF input power conditions and to provide the recommendations for the specifications of the mechanical system upgrade to meet its control performance requirements. Due to different offsets among the instrument sensors, it is difficult to perform a model validation with a traditional method during the model behavioral validation process. In this paper, a new validation scheme for simulation models is proposed. The approach is to use fuzzy logic techniques and build a Validation Fuzzy Knowledge Base (VFKB) which serves as a repository for all aspects of expected behavior of the simulation model. This enables the automation of the validation activity. A procedure of creation of VFKB for a model is presented.

INTRODUCTION

Computer simulation models are widely being used in problem solving and decision making. A computer simulation model for the Resonance Control Cooling System (RCCS) at Spallation Neutron Source (SNS) has been developed. The primary purpose of this dynamic model is to help understanding the dynamics of the existing mechanical system and its controllability under varies RF input power conditions and further to provide recommendations for the specifications of the mechanical system upgrade to meet its control performance requirements. To a great extent, the degree of the usefulness of a computer simulation model lies in its ability to how accurately predict the behaviour of its "target" system which is under study. The establishment of this confidence is to go through validation process for the computer simulation model with the respect to target system. There is no absolute validity of a model. The goal of the validation process is to gain a reasonable level of confidence so that inferences drawn from the model can be accepted with confidence. The model validation process requires the knowledge from both the model developers and the target system experts. There are ten RCCS subsystems in SNS. Each of them may have different sensor read backs under varies RF power conditions. Their mechanical behaviour and physics principals are the same. A general architecture for a computer simulation model validation environment is desired. In this paper, we report a computer simulation model validation scheme that was developed during the validation process for the RCCS model at SNS.

RCCS MODEL VARIFICATION AND VALIDATION

There are three major activities during the modeling and simulation process together with verification and validation activities for the SNS RCCS. They are abstract model verification, structural model validation and behavioral model validation.

The abstract model verification is to verify the degree of the correctness of the mathematical equation representation used in the simulation code with the respect to the RCCS system. The structure validation is to evaluate the structure of the simulation model with respect to the structure of the RCCS system. The behavioral validation is to evaluate the simulation model behavior with respect to the response of the RCCS system from a set of experimental inputs. See Figure 1 for the overview.

Model Structural Validation

The model structural validation is a relatively straight forward process during a model validation. One should analyse the components of a simulation model and its target system. Then write down the function descriptions for each of these components and evaluate them if they are functionally equivalent in the simulation model code and the target system. A list of the components in RCCS system and their corresponding simulation blocks (modules) are listed in Table 1. [2]

Table 1: RCCS Model Structural Validation Information

RCCS System	RCCS Model	Function Description	Degree of Truth
RF Power	RF Power block	Average RF power dissipated in the cavity depends on the degree of cavity detuning	9.0
Tank/Module	Cavity block	Cavity metal temperature is a product of heat transfer coefficient and heat exchange area of wall cooling channels while the heat in the cavity wall by RF power, dissipated in side of the cavity is about the average of water temperature in the cavity cooling channels	8.0
Cooling	Cooling block	The water flow rate and the water temperature determines amount of cooling effort inside of a cavity	8.0
Heater	Heater block	The heater is only used when CV4 is closed to ensure the water flow going through the heater	2.0
Actuator	Actuator block	A backlash at the end of the actuator simulates the real situation	9.0
3-way Valve	Control Valve block	3-way valve diverts % of water flow to go through the heat exchanger. The time delay wasn't taken into account and the flow limit is.	8.0
Heat Exchanger	Heat Exchanger block	Heat transfer coefficient varies from one RCCS to other. It needs to be measured experimentally	5.0
3-way valve PID	PID block	The PID controller can be simulated exactly to the one used in the field	9.9
2-way valve	Not Implemented	2-way valve controls amount of chilled water going through the heat exchanger	0
2-way valve PID	Not Implemented	2-way valve PID controller to regulate the chilled water flow	0
Pump	Not Implemented	To maintain an adequate flow rate into the cavity and meet the cooling requirements	0
Pump PID	Not Implemented	Automatically adjust pump speed to maintain a fixed flow rate	0

Abstract Model Verification

Abstract model verification is to verify each mathematical equation used in the simulation code with ensuring that the software code faithfully reflects the behaviour that is implicit in the specifications of the conceptual model. We made a list of equations for the components listed in Table 1. Then exam each differential equation with its boundary condition in comparing with target system. It is important to know that it is often too costly and time consuming to determine that a model is absolutely valid over the complete domain of its intended applicability. Instead, tests and evaluations are conducted until sufficient confidence is obtained that a model can be considered valid for its intended application [4].

Model Behavioural Validation

Once the abstract model verification and the model structural validation are conducted, we are ready to perform the last step, model behavioural validation activity. This step is to use a set of predefined experimental inputs, generated by the model developers or the target system experts, to evaluate the model behaviour with respect to the response of the RCCS system. There are ten RCCS systems in SNS. Each of them has the similar response behave, but they deal with inconsistent sensor read backs. We propose a new validation scheme for the model behavioural validation. The approach is to use fuzzy logic techniques to build an expert knowledge base for the model validation process. We discuss this in next section.

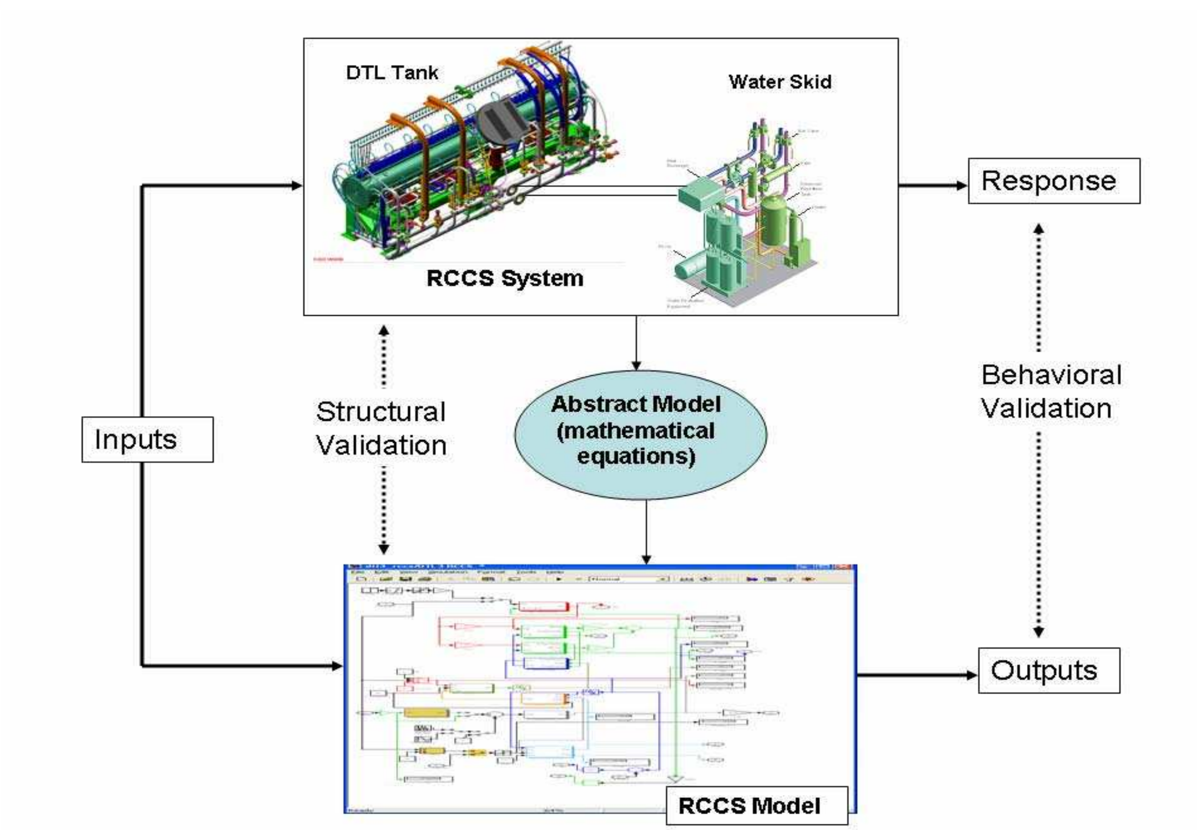

Figure 1: An Overview of RCCS Model Verification and Validation Activities.

FUZZY KNOWLEDGE BASE FOR VALIDATION USE

The model behavioural validation deals with the trend of a model dynamics. It usually can afford to be imprecision and less certainty. The expert knowledge about the behaviour of a RCCS system or its model is most likely with fuzzy variable, such as, "close to zero", "almost in close position", "increase fast", etc. This is the area where fuzzy logic expert system can help. [3]

A validation fuzzy knowledge base consists of a set of fuzzy rules that are representing the relationships of a set of inputs and their expected output responses, which will be used for the model validation process. Similar to a traditional knowledge base, the Fuzzy Validation Knowledge Base (FVKB) for a simulation model is intended to characterize its expected behaviour. [5]

The FVKB can be generated from a union of three disjoint sets of relationships or fuzzy rules and we describe them in the following.

Formal Specifications

These are the relationships that must always hold.

- The 3-way valve open position is almost always >= Zero
- All flow meter readings are almost always >= Zero

Qualitative Specifications

These are the known causal relationships.

- If pump stops, all flow meter readings should be close to zero
- If 3-way valve is in its medium open position, Flow Meter (FT2) should be close to its max
- If 3-way valve moves from small open position to larger, resonance frequency will be increasing when the change of the RF input power is small
- If water temperature increases more, the resonance frequency will reduce more

Observational Specifications

Observe and compare the output responses from the simulation model and the RCCS system while vary the experimental input data. The more similar input data should produce closer output responses.

SUMMARY AND FUTURE WORK

SNS RCCS dynamic model has been recently developed with a collaboration effort. The initial validation of the model has been conducted. Three activities are used in the model verification and validation process: structural validation, abstract verification and behavioural validation. During the model validation process, we learned that it is time costly to perform the behavioural validation step. It is desirable to develop a general model validation procedure and environment. We proposed a new model validation scheme which uses fuzzy logic techniques. We formulated the creation procedure of a fuzzy validation knowledge base and this makes the validation automation possible. A limited test of this scheme for the RCCS model validation has been conducted. More work need to be done before the validation automation can be practically realized.

REFERENCES

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