Evaluation of Functional and Performance Equivalence between Virtual DCS and Real DCS

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1. Introduction

The primary advantage of the MMIS(Man-Machine Interface System) digital twin being developed at the KHNP CRI lies in its ability to simulate real software (such as control logic, server applications, etc.) installed in power plants without any modifications.[1] Therefore, it is anticipated that the MMIS digital twin will be extensively utilized for software verification and validation (V&V), including direct and indirect verification of software, in the event of field Design Change Package (DCP) occurrences due to software design changes during the commissioning stage of the Shin-Kori Unit 5 reactor.

To achieve this, the most crucial aspect is the equivalence between the developed MMIS digital twin and the original MMIS, when using MMIS digital Twin for S/W V&V, with a focus on the equivalence between the virtualized control platform where the software is installed and executed the physical control platform (PLC, DCS).

This paper aims to evaluate the functionality and performance equivalence (or similarity) of the virtual DCS implemented for building the physical control system and MMIS digital twin targeting the korea MMIS of APR1400, which employs an unsafety control system (DCS) platform.

2. Methods and Results

The equivalence between virtual DCS and physical DCS can be categorized into two aspects: functionality and performance.

Functionality was validated through experiments to ensure that the functions operated on the physical (or real) DCS behave identically in the virtual environment. Performance comparison included computational speed, input/output signal processing speed, and output results between the virtual DCS and physical DCS.

2.1 Functional Equivalence Test

The tests conducted for functional equivalence verification are as follows:

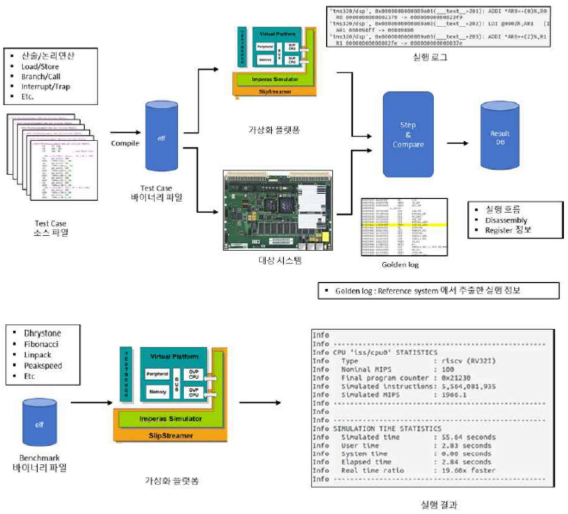
○ DCS Authentication Test: Verify the accurate execution of unique authentication functions during the initial boot of DCS using dedicated tools (System Builder).
○ Control Logic Test: Confirm the downloading of logic via OPEARSYSTEM Workbench, perform online debugging functions, and ensure that the state monitoring transmitted from the virtual controller is accurately displayed in System Builder.
○ Monitoring Test: Verify the transmission of normal monitoring data and status monitoring data according to the transmission cycle.
○ Binding Test: Confirm the data transmission (binding) function between DCSs.
○ Soft Control Test: Modify the values of Normal Monitoring Tags and Fast Monitoring Tags of DCS through soft control, and verify the transmission of modified tag values in monitoring data.
○ I/O Signal Processing Test: Apply input signals through the Virtual DCS Interface SW and confirm the input signals at the input module of the virtual controller.
○ Redundancy Test: Verify if the redundant DCS accurately transmits status information including operational change information in case of operational change conditions, and confirm if the input/output signals are qualitatively processed according to the operational change.
○ SOE Test: Set up Soft SOE that processes events occurring in the logic and link it with digital input module signals to configure SOE in System Builder. Confirm that the processed SOE signals from the virtual controller are transmitted to the SOE server.

2.2 Performance Equivalence Test

For CPU computational processing performance, the Draystone benchmark performance technique is applied. Draystone is one of the benchmark testing methods for testing microprocessor performance, allowing benchmark testing by comparing the performance of microprocessors by required items. Utilizing this Method (or tool), Test Cases are developed, and Test Binaries are generated, which are then executed on both physical and virtual CPUs for comparison and verification of the results.

To verify the accuracy of the virtualization platform, three steps are undertaken:

○ Step 1: Validation of Virtualization Processor ISA (Instruction Set Architecture) Model Accuracy and Reliability.
○ Step 2: Individual Instruction Validation.
○ Step 3: Verification of the operation of each possible form of individual instruction.



```
Info
Info ---------------------------------------------------
Info CPU 'iss/cpu0' STATISTICS
Info   Type                   : riscv (RV32I)
Info   Nominal MIPS           : 100
Info   Final program counter : 0x21230
Info   Simulated instructions: 5,564,081,935
Info   Simulated MIPS         : 1966.1
Info ---------------------------------------------------
Info
Info ---------------------------------------------------
Info SIMULATION TIME STATISTICS
Info   Simulated time         : 55.64 seconds
Info   User time              : 2.83 seconds
Info   System time            : 0.00 seconds
Info   Elapsed time           : 2.84 seconds
Info   Real time ratio        : 19.60x faster
Info ---------------------------------------------------
```

Fig. 1. Response time measurements for Virtual DCS using Draystone benchmark

For I/O response performance, the DCS response time measurement tests conducted on physical DCS are replicated on the virtual DCS. Expected response times for each case are calculated based on segmented intervals, followed by performing the test by measuring actual response times.

2.3 Test Result

In terms of functional testing, consistent results with the original product were confirmed across all eight functionalities. As a result, it was confirmed that functionally the virtual DCS was implemented identically to the real DCS

Regarding performance testing, the CPU computational speed of the virtual controller was observed to execute at a faster rate compared to the physical controller, with identical outcomes. Additionally, the execution speed could be adjusted to match that of the physical controller, resulting in equal or superior performance compared to the original product.

However, in the aspect of interfacing with external input/output signals, while the physical controller seamlessly integrates with external input/output signals via hardwired connections, the virtual controller experiences delays as it communicates with external input/output signals through communication protocols.

At the current stage, it is evident that the MMIS digital twin can be sufficiently utilized for algorithm verification of power plant control logic. However, directly employing the currently developed MMIS digital twin for field device control performance tasks such as PID controller gain validation appears to be challenging.

3. Conclusions

Evaluating the equivalence of virtualization results is notably challenging due to the lack of standardized performance validation methods for virtual systems. So currently, the assessment is qualitative, involving a thorough investigation to identify suitable methods from existing performance validation approaches for conventional computer systems (including embedded systems). There is a pressing need to develop and apply verification methods tailored to our NPP environment in the future.

In the future, efforts will be directed towards aligning the input/output time delays of the virtual controller with those of the physical controller to a comparable level, aiming to enable direct utilization of the MMIS digital twin for field device control performance verification. Additional research will be conducted to achieve this goal.

REFERENCES

[1] Sungjin Lee, Won Woong Ko, “Basic Concepts of APR1400 MMIS Digital Twin using Virtualization Technology”, Transactions of the Korean Nuclear Society Spring Meeting, 2020.