

Enabling the real-time simulation of hydraulic excavators with FPGA technology!



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◆ What type of work do you do?

We conduct research and development on remote, automated, and operator-assisted operation as part of the advanced development of construction machinery, specifically hydraulic excavators. At our company, we are developing remote and autonomous operation technologies to promote people-centered ways of working, with the goal of creating construction sites where people can thrive, which all fits under the theme of transforming worksites into places where anyone can work. Since 2015, we have been conducting research and development on advanced technologies such as remote, automated, and operator-assisted operation in collaboration with research partners, including Hiroshima University. Through our collaborative research and development efforts, we're promoting the adoption of model-based development (MBD) and conducting R&D using simulation technologies. In the past, we used simulation-based development to create our Series-8 hydraulic excavator, which we introduced in 2008. Compared with previous models, it achieved a 20% improvement in energy efficiency. Today, we're also incorporating control systems into our simulation-based development, helping to accelerate product development.

◆ Tell us about the challenges you face in your work

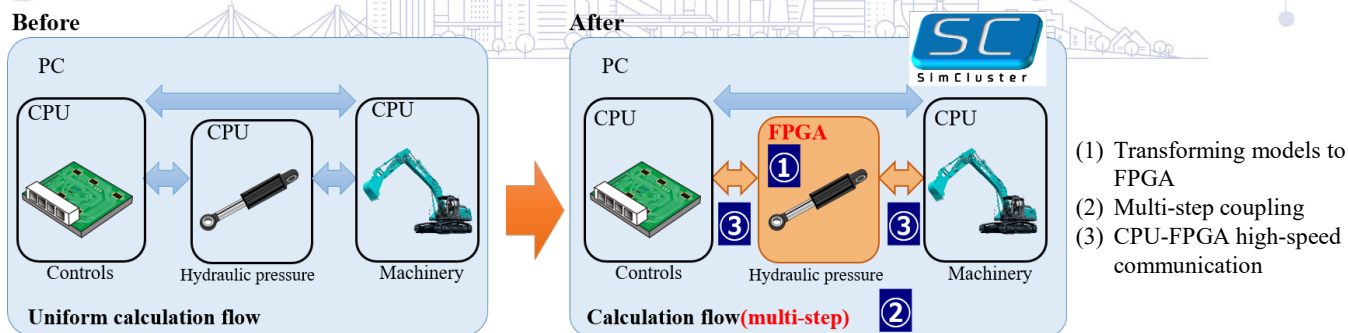
As we expanded our use of MBD and simulation-based development, we wanted to use a more versatile development platform. With that in mind, we built our development environment around MATLAB/Simulink. Using MATLAB/Simulink, we built an integrated simulation environment that combined the hydraulic system, mechanical components, and electronic controls, and applied it to our R&D efforts. However, we eventually ran into the limitations of real-time performance. To give you a concrete example, simulating a single 18-second digging cycle for a 20-ton-class hydraulic excavator took an entire day to run.

At the time, the gap to achieving real-time performance was simply too great, and we didn't have a way to bridge it. If you don't get the simulation results until the next day, development inevitably takes longer, so it does little to improve development efficiency or shorten lead times. In human-focused R&D, we also evaluate how machines can assist operators and how systems and machines work together. In those evaluations, the simulation of the machine must respond to the operator's inputs in real time. Otherwise, the evaluation simply isn't valid. In particular, in our collaborative research with Hiroshima University, we were working on technologies that enable better coordination between people and machines. However, when the project began, we weren't able to deploy the simulation environment used for the Series-8 model at the university while maintaining real-time performance. As a result, the university's research technologies could only be evaluated on the actual machine. This meant traveling to wherever the machine was located to carry out the evaluation, then returning to the university to analyze the data, revise the implementation software based on the results, and finally validate the changes with another round of testing on the machine. This iterative process was extremely time-consuming. Another challenge in advancing our collaborative research with the university was that, because evaluations could only be performed on the actual machine, the professors and students involved in the project couldn't evaluate the system firsthand by operating it themselves. It's for that reason that we need simulation technology capable of real-time operation to push our R&D efforts along.



SK210LC-11 (European-spec model)
(source: Kobelco Construction Machinery Ltd.)

Achieving simulations in real-time speed for models that previously required more than two hours



◆What were the key requirements for solving these issues?

To evaluate technologies that assist the operator, the simulation has to run in real time. Without real-time performance, meaningful evaluation isn't possible, so that's one of our key requirements. In particular, for the hydraulic excavators we develop, the hydraulic circuit is highly nonlinear and computationally intensive. At the same time, the mechanical system and the hydraulic circuit have to run in sync in real time.

◆Tell us why you chose TTDC

It all started when we were looking into technologies that could support simulation-based development. At the Society of Instrument and Control Engineers' (SICE) Multi-Symposium on Control Systems (MSCS), we came across TTDC, where they told us, "We can do real-time simulation." When we first began developing a real-time simulation environment, we didn't even know whether the overall system would be possible. However, by starting with small-scale validation, gradually expanding the scope, and working through various technical challenges together with TTDC, we became confident that we could achieve our goals. That's why we chose TTDC. From a technical standpoint, another major factor was that TTDC took the time to develop a thorough understanding of the hydraulic system used in our excavators. What we especially appreciated was that, even though this was a technically challenging area that was new to TTDC, they approached it with sincerity, took the time to understand the technology in depth, and worked through it together with us.

◆What were the benefits of adoption?

The evaluation of the new features planned for our next model is already well underway. We can run the simulation and then immediately verify the results through testing on the actual machine, which has dramatically sped up the evaluation process. Since the simulation runs in real time, it lets us evaluate the system in a way that's very similar to using the actual machine. That's what I feel makes simulation so valuable. When we first began collaborating with the university, theoretical validation was carried out using the actual machine. An engineer would first learn the theory from the professor, understand it, implement it in software, deploy it to the machine, and then conduct testing. Just one development cycle took at least a week. Under those conditions, we could only conduct one trial per week. If one trial failed, we would have to spend another week on it. Today, the process is the same up to the point of learning the theory and implementing it.

After that, however, we first build a model and verify it using real-time simulation. Depending on the implementation, we can prepare several model variations and evaluate them in a single round of testing before moving on to the actual machine. As a result, we're able to confirm our research results much more quickly. Another benefit is in advanced feature development. In the past, we had to wait several months for the actual machine to become available before we could begin evaluation. Now, we can carry out desktop simulation in parallel without having to wait. As a result, once the actual machine has been modified and brought to the test site, we're sometimes able to begin testing as early as the next day. In addition, real-time simulation allows us to evaluate multiple design alternatives in advance, enabling front-loading of development through a model-based approach. The simulation can't match the actual machine perfectly, but it captures the overall behavior quite well. Although the simulation isn't intended to provide perfect absolute accuracy, it reproduces the overall system behavior well enough to support relative evaluation and identify positive trends.

◆Could you tell us about your plans for the future?

Going forward, we plan to further leverage simulation and MBD to improve development efficiency across the entire process, from R&D to product development. We also want to make simulation more flexible and easier to use. For example, simplifying design changes and accelerating development through the use of cloud-based virtual environments. We also want to leverage real-time simulation to expand our human-centered research and development, particularly in areas such as operator interaction and human factors. Our goal is to build a development environment that enables professors and students involved in collaborative research to participate more actively.



Back row from the left: Mr. Nanjo, Mr. Yamashita, and Mr. Koiwai
Front row from the left: Mr. Shikata (TTDC), Mr. Senda (TTDC)