







Model Exchange because the communication time between tools is an important factor.

#### 4 Control Parameters Optimization

We use the coupled model using FMU to explore design parameters for control.

In this study, as an example of the control robustness against the difference in the operating environment of the working machine, we optimized control parameters for two cases with different Bucket mass parameters.

The operating conditions are the same as the series of operations shown in Figure 5.

Table 2 outlines the optimization calculation.

**Table 2.** Optimization Outline

Bucket Condition	<ul style="list-style-type: none"> <li>•Payload off</li> <li>•Payload 50kg</li> </ul>
Design variable	Controller gain and time constant for each cylinder (Total 6 parameter)
Objective	Minimize cylinder length error $\varepsilon$

We set the error  $\varepsilon$  between the objective and the target value of cylinder length as following equation.

$$\varepsilon = \sqrt{\frac{1}{n-1} \sum_{n=1}^n (y_{real} - y_{obj})^2}$$

In the design exploration, we ran DOE calculation at the beginning to create an approximate model from the result. DOE was performed by Latin Hypercube, and approximate model was created using RBF (Radial Basis Function). Optimization was carried out to minimize the error defined by the equation above using the created approximate model. The optimization method was NCGA (Neighborhood Cultivation Genetic Algorithm). These workflows were created using Isight. Figure 8 shows the outline of the design search.

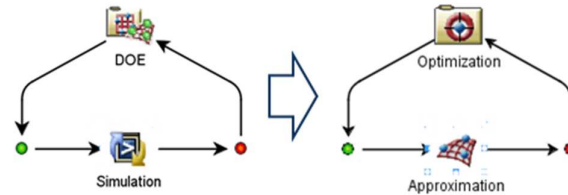
Figure 9 shows the comparison of approximate model and actual model. The approximate model is created based on DOE results by RBF method. The result of approximate model is in good agreement with the result of actual model, so the approximate model can be applied to optimization.

Figure 10 to Figure 13 show the calculation results.

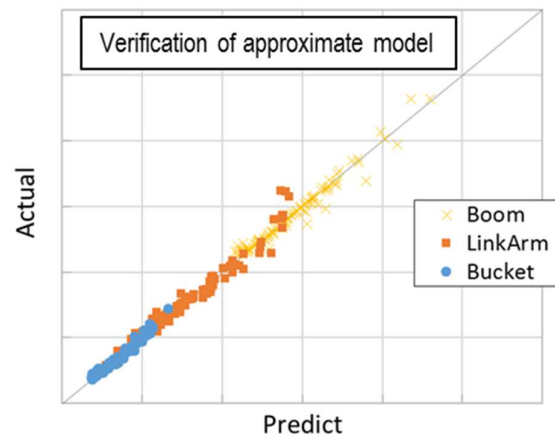
Figure 10 and Figure 11 show the time domain data of the difference with respect to the target value of the Boom cylinder length, and Figure 12 and Figure 13 show the time domain data of the target value and the calculated cylinder length.

As can be seen from Figure 10 and Figure 11, the error with respect to the target value becomes smaller by using the optimized parameters.

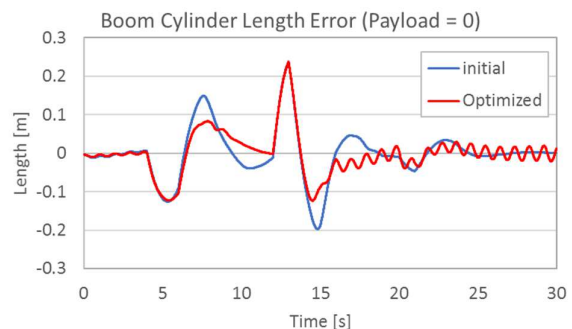
We can also confirm the effectiveness of the optimization by comparing the cylinder lengths in Figure 12 and Figure 13.



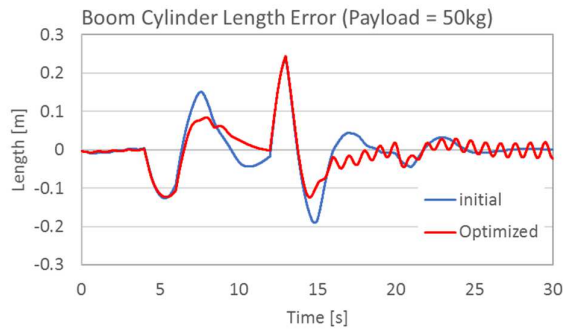
**Figure 8.** Workflow of optimization in Isight



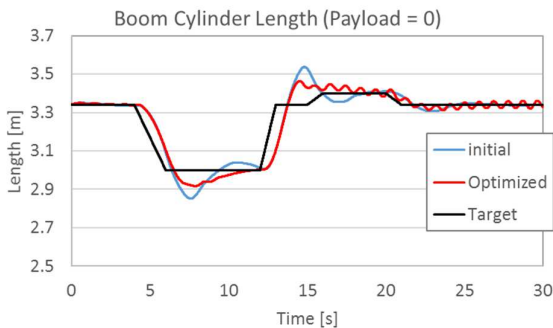
**Figure 9.** Verification result of approximate model



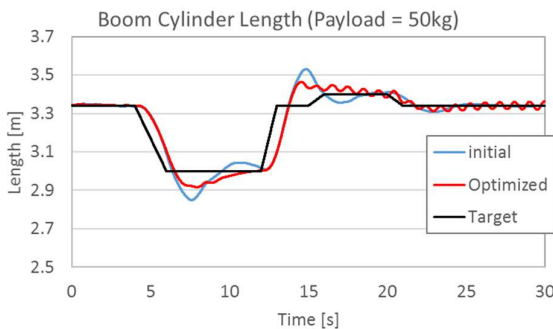
**Figure 10.** Boom Length Error (Payload off)



**Figure 11.** Boom Length Error (Payload 50kg)



**Figure 12.** Boom Length (Payload off)



**Figure 13.** Boom Length (Payload 50kg)

## 5 Conclusion

For a construction machine, we modeled a system including hydraulic controller with 1D simulation tool and mechanism analysis software and created an integrated simulation model using FMU.

In this case, it turned out that FMU Model Exchange worked efficiently for the optimization of control parameters.

In this study, we performed design space exploration on control parameters, but we think that it can be applied not only to control parameters but also to

dimensioning components such as the shape of structural parts.

As a conclusion, we consider that the use of the system model with FMU is effective for the design search at the early stage of development where we need to evaluate systems performance coupling different disciplines efficiently.

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