Modeling method of fluid-structure interaction system based on deep neural network

Renkun Han[1], Jiaoxi Du[1], Xin Li[1], Ziyang Liu[1], Gang Chen[1,†]
[1,†] State Key Laboratory for Strength and Vibration of Mechanical Structures,
Shannxi Key Laboratory for Environment and Control of Flight Vehicle,
Xi'an Jiaotong University, Xi'an 710049, China

[1,†]aachengang@mail.xjtu.edu.cn

Abstract

Fluid-structure interaction analysis has high computing costs when using computational fluid dynamics. These costs become prohibitive when optimizing the fluid-structure interaction system, because of the huge sample space of structural parameters.[1] In order to establish a fast prediction method for nonlinear fluid-structure interaction system, a modeling framework of fluid-structure interaction system based on deep neural network was constructed. In this framework, a deep neural network model is used instead of the traditional fluid dynamic solver to predict the unsteady flow field state during the interaction process. The deep neural network model can predict the flow field state at the next time step based on the current flow field state and structural boundary displacement. Extract the pressure distribution on boundary surface from the flow field predicted by the deep neural network, and transmit it to the structural dynamic solver as input data to get the structural motion displacement. Then, the deep neural network can continue to predict the flow field state at the next time step based on the predicted flow field state and the structural motion displacement output by the structural dynamic solver. The combination of deep neural network model and structural dynamics solver forms a complete fluid-structure interaction system response prediction model, which can quickly predict the structural movement process and all time-steps flow field state in the fluid-structure interaction process.

Take a two-dimensional cylinder vortex induced vibration system as an example. The deep neural network based interaction model is programmed and trained using MindSpore Lite tool [2] developed by Huawei. The deep neural network based interaction model is trained using the data of the fluid-structure interaction system at different reduced velocity. Only providing the initial state of the flow field and structural motion, the trained deep neural network based interaction model can obtain the structural vibration process and flow field evolution process at low computational cost. Fig. 1 shows the variation of structural displacement over time. It can be seen that the deep neural network based interaction model can predict the entire development process of cylinder vibration, starting from the initial position and gradually increasing in amplitude, until reaching a stable vibration state. Although there is a phase difference between the initial predicted results and the true values, the final vibration amplitude and frequency are in good agreement with the true values. Under different reduced speed conditions, the predicted structural amplitude and frequency are all in good agreement with the true values. Fig. 2 shows the predicted results of the flow field state at four time points represented by dashed lines in Fig. 1. The first column shows the predicted flow field state after 60 time-steps. At this stage, the structural amplitude is very small, so the flow field state remains similar to the initial input steady flow field.

†Corresponding Author : Gang Chen, Tel: +86-18166454808, E-mail: aachengang@mail.xjtu.edu.cn

There is no obvious vortex shedding phenomenon at the trailing edge of the cylinder. The second and third columns display the flow field state as the amplitude gradually increases. The length of the tail vortex is significantly decreasing.

Keywords: Fluid-structure interaction; Unsteady; Deep learning; Neural network; Fast prediction

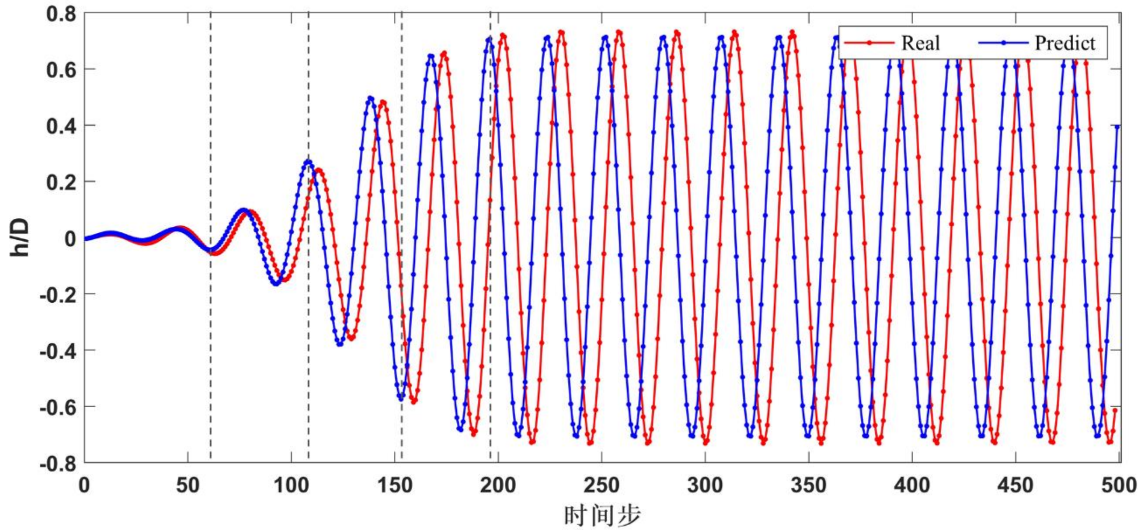

Fig. 1 Model predicted structural motion over time

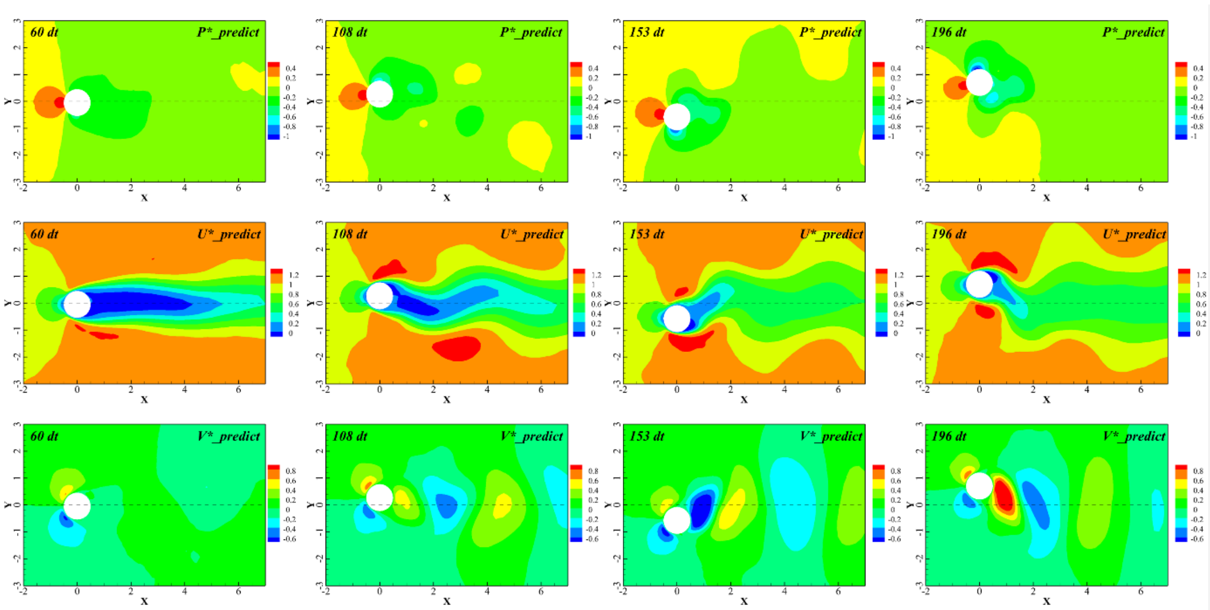

Fig. 2 Model predicted flow field state at different time step

References

[1] H. Han, R., et al. "Deep neural network based reduced-order model for fluid–structure interaction system." Physics of Fluids, 34(7), April 2022.

[2] MindSpore. https://www.mindspore.cn/