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Adaptive neural network based boundary control of a flexible marine riser system with output constraints

Key words: Marine riser system; Partial differential equation; Neural network; Output constraint; Boundary control; Unknown disturbance

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Motivation

1. Marine risers with flexible structures are much lighter and have better flexibility and deformations than the ones with ordinary rigid structures.

2. Marine riser systems are always accompanied by unknown nonlinear disturbances which lead to instability of the dynamic system, and it is difficult to obtain an accurate model of these nonlinear disturbances.

3. Many industrial systems may encounter various constraints. Excessive outputs may cause damages to the system hardware.

4. The radial basis function neural network (RBFNN) is powerful in approximating nonlinear disturbances of flexible robot manipulators.

Method

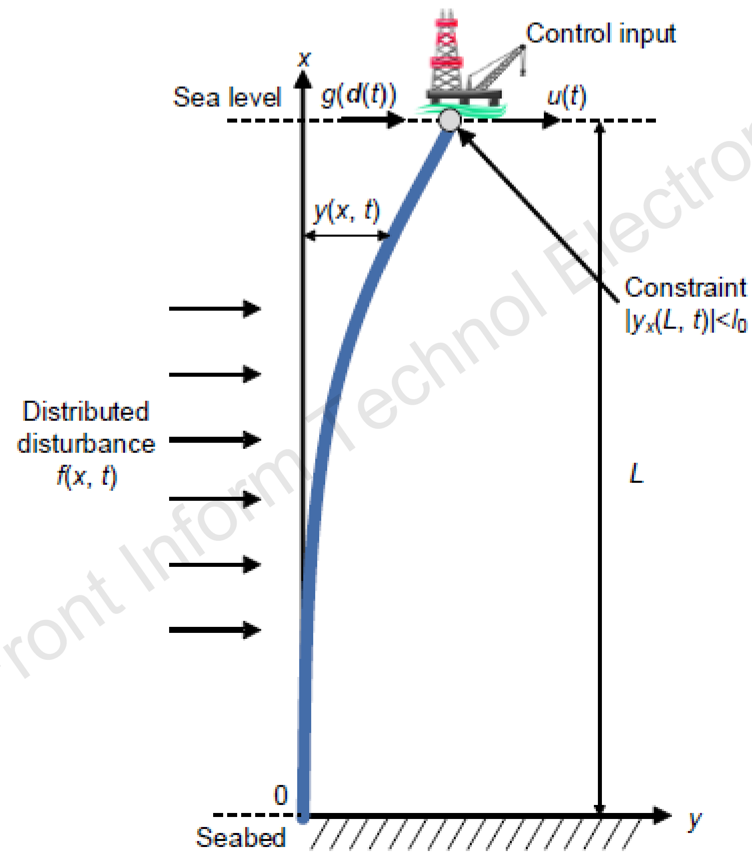

Fig. 1 A typical marine riser system

Method (Cont'd)

Considering a typical marine riser system using the Euler–Lagrangian equation and Hamilton principle, the marine riser system can be obtained as the following governing equation:

$$\rho y_{tt}(x,t) + E_I y_{xxxx}(x,t) - T y_{xx}(x,t) - f(x,t) = 0,$$
$$\forall (x,t) \in (0,L) \times [0,\infty).$$

The boundary conditions are

$$y(0,t) = y_x(0,t) = y_{xx}(L,t) = 0,$$

$$\begin{aligned} & - E_I y_{xxx}(L,t) + T y_x(L,t) \\ = & u(t) - M y_{tt}(L,t) - g(d(t)), \text{ with } \forall t \in [0,\infty). \end{aligned}$$

Method (Cont'd)

The main objective of this study is to control vibrations of a flexible marine riser system with barrier constraints. We need the boundary output $y_x(L,t)$ to satisfy the constraints, that is, $\left|y_x(L,t)\right| < l_0$.

Since $g(\boldsymbol{d}(t))$ is unknown, we approximate this unknown function in the form of an RBFNN:

$$g(\boldsymbol{d}(t)) = \boldsymbol{W}^{\mathrm{T}}(t)\varphi(\boldsymbol{d}(t)) + \epsilon_{\boldsymbol{W}} \; .$$

The output of RBFNN is

$$\hat{g}(\boldsymbol{d}(t)) = \hat{\boldsymbol{W}}^{\mathrm{T}}(t)\varphi(\boldsymbol{d}(t)).$$

Main results

Diagram of the proposed control strategy is presented in Fig. 2 to illustrate the overall design of the flexible marine riser system.

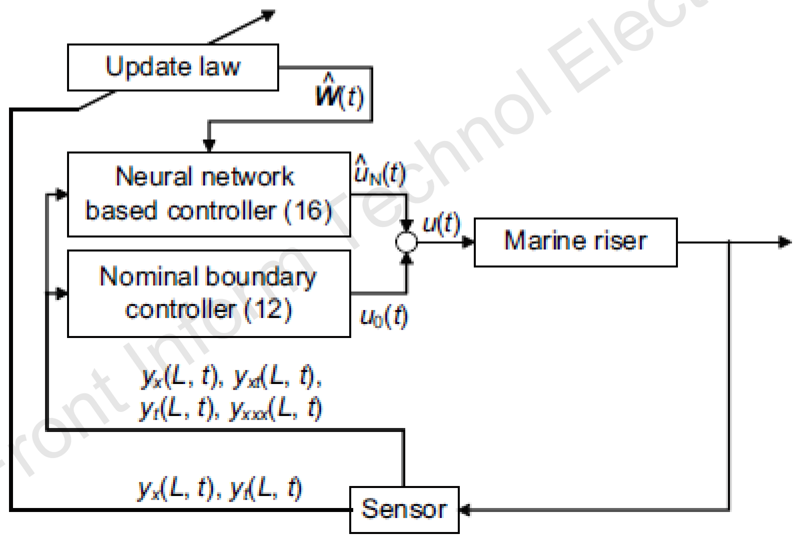

Fig. 2 Diagram of the proposed control strategy

Main results (Cont'd)

The boundary controller $u_0(t)$ is designed to guarantee that the constraint of the boundary output and an adaptive neural network based boundary controller $\hat{u}_N$ realized by RBFNN can be constructed as follows:

$$\begin{aligned} u(t) =& u_0(t) + \hat{u}_{\mathrm{N}}(t) \\ =& -k_1\phi(t) - k_3 y_{xt}(L,t) - E_I y_{xxx}(L,t) \\ & + T y_x(L,t) - \Bigg(k_2\phi(t) - E_I y_{xxx}(L,t) \\ & + T y_x(L,t) + M\phi(t)\frac{y_x(L,t)y_{xt}(L,t)}{l_0^2 - y_x^2(L,t)} \Bigg) \\ & \cdot \left(\ln \frac{2l_0^2}{l_0^2 - y_x^2(L,t)} \right)^{-1} + \hat{W}^{\mathrm{T}}(t)\varphi(d(t)). \end{aligned}$$

The update law of $\hat{W}(t)$ is designed as

$$\dot{\hat{W}}(t) = -\beta \ln \frac{2l_0^2}{l_0^2 - y_x^2(L,t)} \phi(t)\varphi(d(t)) - k_4 \hat{W}(t) \; .$$

Simulation results

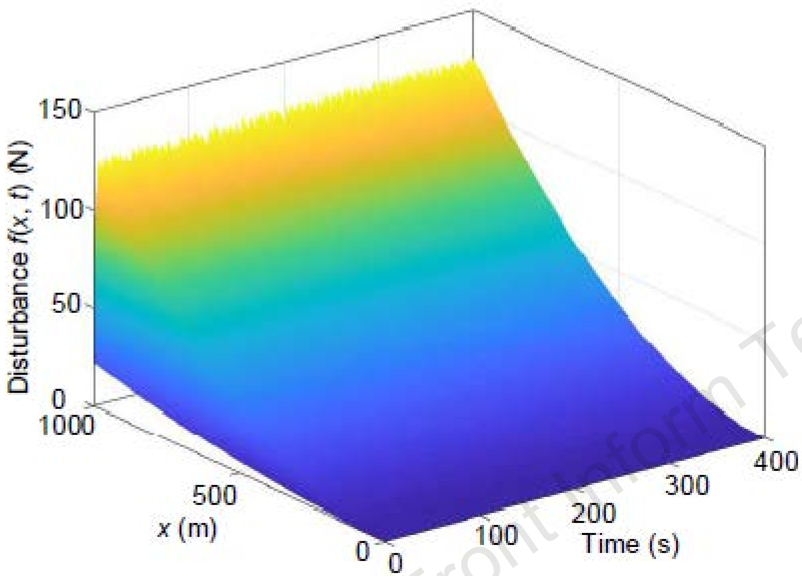

Fig. 3 Ocean distributed disturbance

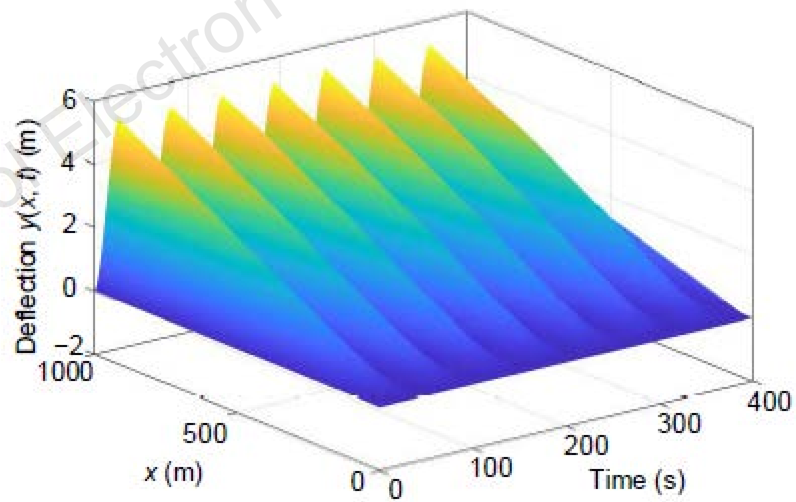

Fig. 4 Evolution of the marine riser without control

Simulation results (Cont'd)

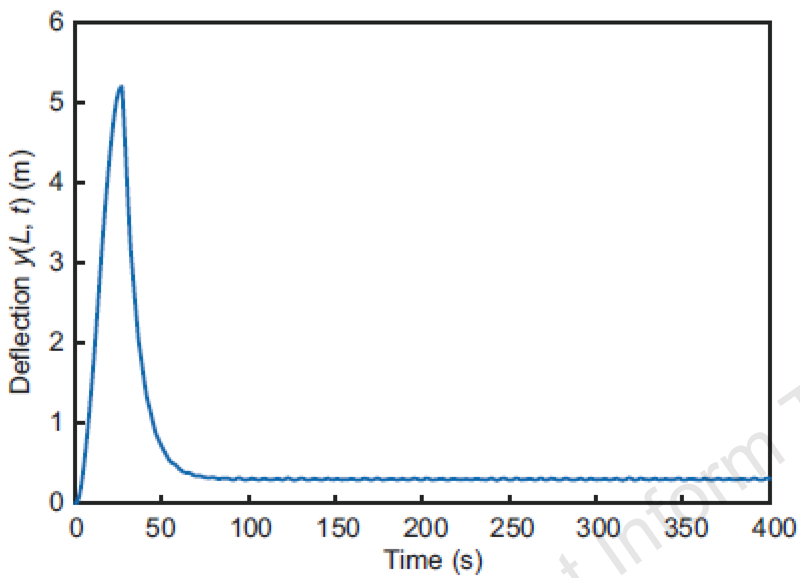

Fig. 7 Evolution of $y(L,t)$

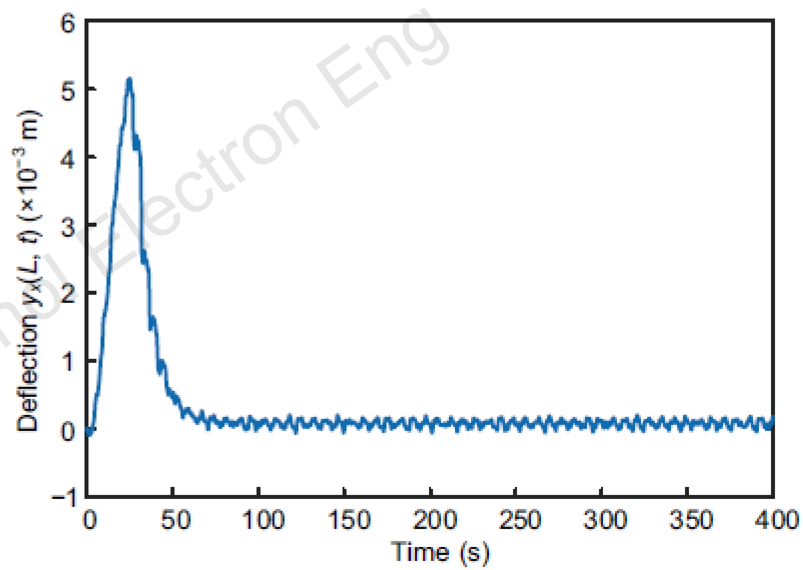

Fig. 8 Evolution of $y_x(L,t)$

Simulation results (Cont'd)

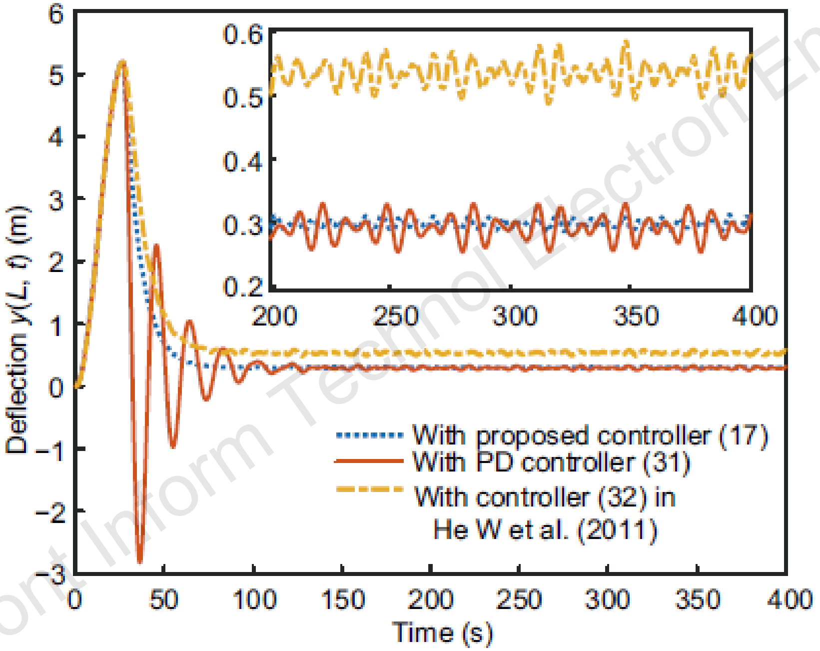

Fig. 9 Comparison of the effectiveness of three controllers (control input is added at 26.76 s)

Conclusions

1. An RBFNN has been used to approximate unknown nonlinear disturbances and deal with model uncertainty on the stability of the riser.
2. With the proposed controller, the flexible marine riser system can be ensured to satisfy barrier constraints.
3. Based on the Lyapunov function, the uniform boundness of the flexible marine riser has been proved.