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# Observer design for a nonlinear two-dimensional pool boiling system

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## 1 Introduction

In pool-boiling systems heat is extracted from a heater by a pool of boiling liquid. The heat flux between heater and fluid is highly nonlinear with respect to heater temperature, described by  $q_F(T_F)$  (Figure 1) and results in a highly unstable regime which must be stabilised to allow for high heat removal rates. This can be accomplished by a control law based on the (nonmeasurable) spectral modes of the heaters temperature field [1]. Application of this control law requires an observer for the temperature profile of the heater.

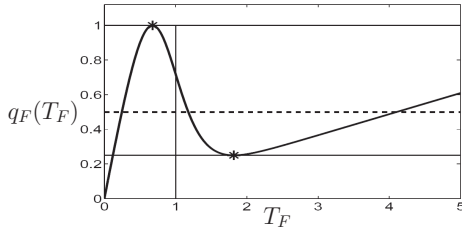


Figure 1 Nonlinear heat flux  $q_F$  as function of interface temperature  $T_F$ .

## 2 Pool boiling model description

The heat transfer in the 2D rectangular nondimensional heater  $\mathcal{H} := \{(x,y) \in [0,1] \times [0,D]\}$ , see Figure 2, is considered. Its temperature field  $T(x,y,t)$  is described by

$$\frac{\partial T}{\partial t}(x,y,t) = \kappa \nabla^2 T(x,y,t). \quad (1)$$

The boundary conditions comprise adiabatic, i.e. perfectly isolated, sidewalls on  $\Gamma_A := \{(x,y)|x=0,1\}$ , a controlled heat supply on  $\Gamma_H := \{(x,y)|y=0\}$  and the nonlinear heat extraction on  $\Gamma_F := \{(x,y)|y=D\}$ , i.e.

$$\frac{\partial T}{\partial x}\Big|_{\Gamma_A} = 0, \quad \frac{\partial T}{\partial y}\Big|_{\Gamma_H} = -\frac{1+u(t)}{\Lambda}, \quad \frac{\partial T}{\partial y}\Big|_{\Gamma_F} = -\frac{\Pi_2 q_F(T_F)}{\Lambda}. \quad (2)$$

Here  $T_F(x) := T(x,D)$  is the fluid-heater interface temperature,  $\Lambda$ ,  $D$ ,  $\Pi_2$  and  $\kappa$  are positive parameters,  $q_F(T_F)$  is the boiling curve and  $u(t)$  is the input, i.e. an additional heat supply at the bottom of the heater, see [1].

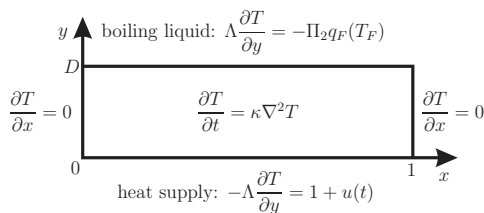


Figure 2 Two-dimensional rectangular heater.

## 3 Observer design

The temperature can be measured at  $R+1$  points on the heater surface, given by  $\tilde{x}_r = r/R$ ,  $r=0, \dots, R$ , i.e. the system output equals  $y_r = T_F(\tilde{x}_r)$  for  $r=0, \dots, R$ . The observer is designed to be a copy of the system with output injection only on the boundary condition where the measurements are available. The obtained observer is given by (1) and (2) with the state  $Z(x,y,t)$ , i.e. the estimate of  $T(x,y,t)$ , instead of  $T(x,y,t)$  and with the boundary condition on  $\Gamma_F$  as

$$\frac{\partial Z}{\partial y}\Big|_{\Gamma_F} = -\frac{\Pi_2 q_F(Z_F)}{\Lambda} + \sum_{r=0}^R p_r(x) (T_F(\tilde{x}_r) - Z_F(\tilde{x}_r)), \quad (3)$$

with  $p_r(x)$  the observer gain functions. The observer error dynamics of  $E = T - Z$  are analysed by linearisation of system and observer, with which local stability of the nonlinear error dynamics can be obtained. Figure 3 shows the evolution of the output, for  $R=2$ , meaning the output equals  $T(0,D,t)$ ,  $T(0.5,D,t)$  and  $T(1,D,t)$ . The initial system state equals a uniform field of  $T \approx 4$ , whereas the initial observer state equals zero. Although the initial differences between system state, observer state and non-uniform equilibrium are large, the observer states converge to the system states and the equilibrium is stabilised.

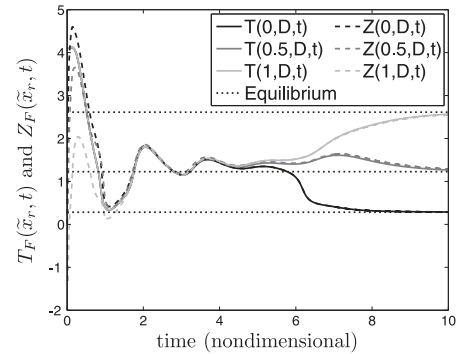


Figure 3 Evolution of the system output and the observer output.

## 4 Conclusion

An observer for a nonlinear PDE system is designed. The closed-loop system is stabilised by the control law discussed in [1] and this observer, even for large initial perturbations.

## References

- [1] R. van Gils, et al. Feedback stabilisation of a two-dimensional pool-boiling system by modal control. *Automatica*, submitted for publication, 2010