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A model-free control strategy for an experimental greenhouse with an application to fault accommodation

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ABSTRACT

Writing down mathematical models of agricultural greenhouses and regulating them via advanced controllers are challenging tasks since strong perturbations, like meteorological variations, have to be taken into account. This is why we are developing here a new model-free control approach and the corresponding "intelligent" controllers, where the need of a "good" model disappears. This setting, which has been introduced quite recently and is easy to implement, is already successful in many engineering domains. Tests on a concrete greenhouse and comparisons with Boolean controllers are reported. They not only demonstrate an excellent climate control, where the reference may be modified in a straightforward way, but also an efficient fault accommodation with respect to the actuators.

1. Introduction

Table 1 in Callais (2006) shows that already a few years ago a large percentage of agricultural greenhouses were computerized. The corresponding automated microclimate regulation should not only improve the production and its quality but also reduce pollution and energy consumption. Most of the existing control approaches, like adaptive control, predictive control, optimal control, stochastic control, nonlinear control, infinite dimensional systems, PIDs, On/Off, or Boolean, control, fuzzy control, neural networks, soft computing and expert systems, have been employed and tested. The literature on the modeling and control of greenhouses is therefore huge. See, *e.g.*,:

- the books by Medjber (2012), Ponce et al. (2014), Rodríguez et al. (2015), Urban and Urban (2010), Van Straten et al. (2010), Von Zabeltitz (2011); and the references therein,
- the papers and memoirs by Aaslyng et al. (2005), Arvantis et al. (2000), Balmat and Lafont (2003), Bennis et al. (2008), Blasco et al. (2007), Caponetto et al. (2000), Cate and Challa (1984), Critten and Bailey (2002), Cunha et al. (1997), Dong et al. (2013), Duarte-Galvan et al. (2012), El Ghoumari et al. (2005), Fourati (2014), Gruber et al. (2011), Ioslovich et al. (2009), Kimball (1973), Kittas and Batzanas (2007), Lafont and Balmat (2002), Pasgianos et al. (2003), Pessel and Balmat (2005), Pessel et al. (2009), Piñón et al. (2005), Salgado and Cunha (2005), Shamshiri and Ismail (2013), Speetjens et al. (2009), Tchamitchian et al. (2006), Viard-Gaudin (1981), Zhang (2008); and the references therein.

Let us summarize, perhaps too briefly, some of the various control aspects which were developed in the above references (see, also, Fig. 1):

- writing down a "good" model, which is necessarily nonlinear, either via physical laws or via black box identification, leads to most severe calibration and robustness issues, especially with respect to strong weather disturbances, which are impossible to forecast precisely,
- for multi-models appropriate control laws are difficult to synthesize,
- "conventional" PID and On/Off techniques, which preclude any mathematical modeling, are therefore the most popular in industrial greenhouses, although:

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– they are difficult to tune,
– their performances are far from being entirely satisfactory.

Here, an experimental greenhouse is regulated via a new approach, called *model-free control* (Fliess and Join, 2013), and their corresponding *intelligent* controllers, where:

- any need of a mathematical model disappears,
- the flaws of conventional PID and On/Off techniques vanish.

It should be emphasized that this setting (which is less than ten years old):

- has already been most successfully applied in a number of practical case-studies, which cover a large variety of domains (see the references in Fliess and Join, 2013, 2014),
- is easy to implement (Fliess and Join, 2013; Join et al., 2013).

Besides excellent experimental results, a straightforward fault tolerant control with respect to actuators is a quite exciting byproduct. It should be emphasized here that fault accommodation for greenhouse control has unfortunately not been very much investigated until now (see nevertheless Bontsema et al., 2011).

Our paper is organized as follows. Sections 2 and 3 summarize respectively model-free control and actuator fault accommodation. Our experimental greenhouse system and its climate management problem are described in Section 4. Section 5 displays our experimental results with our very simple intelligent controller. Comparisons with a classical Boolean controller are found in Section 6. The efficiency of our method, is further confirmed in Section 7 where the temperature references are modified. Section 8 deals with fault accommodation. Some concluding remarks are provided in Section 9.

When compared to the two first drafts of this work, which appeared in conferences (Lafont et al., 2013, 2014), this paper:

- is proposing a much simpler control synthesis than in Lafont et al. (2013),
- gives a much more detailed review of model-free control than in Lafont et al. (2013, 2014),
- reports, contrarily to Lafont et al. (2013, 2014):
  – the hygrometry control,
  – the time evolution of F in Eq. (1).

2. Model-free control and intelligent controllers[1]

2.1. The ultra-local model

For the sake of notational simplicity, let us restrict ourselves to single-input single-output (SISO) systems.[2] The unknown global description of the plant is replaced by the *ultra-local model*:

$$\dot{y} = F + \alpha u \tag{1}$$

where

- the control and output variables are respectively u and y,
- the derivation order of y is 1 like in most concrete situations,
- $\alpha \in \mathbb{R}$ is chosen by the practitioner such that αu and $\dot{y}$ are of the same magnitude.

[1] See Fliess and Join (2013) for more details.
[2] See also Section 5.

Table 1
Percentage distribution of surfaces for the soilless crop greenhouses in France in 2005.

Climate control			
Without	Manual	Automated	Computerized
6%	7%	20%	67%

The following comments might be useful:

- Eq. (1) is only valid during a short time lapse. It must be continuously updated,[3]
- F is estimated via the knowledge of the control and output variables u and y,
- F subsumes not only the unknown structure of the system, which most of the time will be nonlinear, but also of any disturbance.[4]

Remark 2.1. The general ultra-local model reads

$$y^{(\nu)} = F + \alpha u$$

where $y^{(\nu)}$ is the derivative of order $\nu \geqslant 1$ of y. When compared to Eq. (1), the only concrete case-study where such an extension was until now needed, with $\nu = 2$, has been provided by a magnetic bearing (see De Miras et al., 2013). This is explained by a very low friction (see Fliess and Join, 2013).

2.2. Intelligent controllers

Close the loop with the following *intelligent proportional-integral controller*, or *iPI*,[5]

$$u = -\frac{F - \dot{y}^* + K_P e + K_I \int e}{\alpha} \tag{2}$$

where

- $e = y - y^\star$ is the tracking error,
- $K_P,\ K_I$ are the usual tuning gains.

When $K_I = 0$, we obtain *intelligent proportional controller*, or *iP*, which will be employed here:

$$u = -\frac{F - \dot{y}^* + K_P e}{\alpha} \tag{3}$$

Combining Eqs. (1) and (3) yields:

$$\dot{e} + K_P e = 0$$

where F does not appear anymore. The tuning of K_P is therefore quite straightforward. This is a major benefit when compared to the tuning of "classic" PIDs (see, *e.g.*, Åstrom and Hägglund, 2006; O'Dwyer, 2009, and the references therein). Note moreover that, according to Section 6.1 in Fliess and Join (2013), our iP is equivalent in some sense to a classic PI controller. The integral term in the PI controllers explains why steady state errors are avoided here with our iP.

[3] The following comparison with computer graphics, which is extracted from Fliess and Join (2013), might be enlightening. Reproducing on a screen a complex plane curve is not achieved via the equations defining that curve but by approximating it with short straight line segments. Eq. (1) might be viewed as a kind of analogue of such a short segment.
[4] See also the recent comments by Gao (2014).
[5] The term *intelligent* is borrowed from Fliess and Join (2013), and from earlier papers which are cited there.