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IDENTIFICATION AND MODELLING OF THE AGRICULTURAL GREENHOUSE IRRIGATION SYSTEM

Abstract:

Currently in Tunisia, greenhouses have a great prime importance in the sense that they contribute to the creation of a microclimate in term of hygrometric humidity, the vegetal cover and the irrigation favorable to the tomato plant needs in the greenhouse.

As farmers, we noticed that irrigation forms a nonlinear system difficult to order. It is formed of three components that are: pressure, flow and soil humidity. The lack of a physical relation linking these three factors makes the problem hard to control. To establish a compromise between these factors, we must be helped by the identification of this system by considering it as a black box. This model exit must be as close as possible to the real system according to a fixed criterion.

This labor is achieved in order to conceive, predict, order and simulate the irrigation system thanks to a tool box « ident » under Matlab.

Key words: nonlinear system, black box, model, entry, exit, tool box.

1. Introduction

To order Controlling and stimulating, complex systems are difficult to achieve without mathematical relations, linking the entries of this system to their exits. To solve this problem, we focused on the black box system and the observation of entries and exits. By mathematically formulating relations between the different variables of this linear, nonlinear, continued or discreet, specific or stochastic system, we get a model which helps us to simulate, predict and control industrial processes.

This model is obtained via two approaches: that of knowledge or grey box, and that of entry-exit or identification by black box. The obtained model must reproduce at best the system reaction, in all the useful conditions of the system function. The validity of the model is obtained following its comparison according to the observed information and used for identification, to the data first and to the usage background (frequency band, entry level…). To control our irrigation system for the greenhouse tomato plant and with the help of the agriculture expert concerning the needs of that plant the variations levels of pressure, flow and soil humidity in percentage, the « Matlab software» makes easier that systems identification, thanks to a graphic tool box, a group of commands and functions.

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2. Identification generalities

To identify a system is to determine, from the available information related to the system entry-exit, a mathematical model belonging to a same model class, which, when subjected to the same demands as the initial system, must give answers considered as equivalent because of our objectives and the wished precision.

Practically, the identification targets the model determination used to simulate, order or regulate a process rather than a command and regulation device for a greenhouse irrigation system. This model is expected to act in the opposite way of the diverse disturbance, in order to guarantee the best conditions of growth development.

The management of the irrigation devices and consequently the irrigation system control needs implementing regulators which fit the farmer demands that is to say, keep the soil humidity in the farming desired limits with a minimum energy consumption to improve the cost price.

The regulator simulation is essential before implementing it. This operation needs a model that must be trustworthy and that can better characterize the dynamic behavior of the irrigation system.

The parametric identification of a system, by using the adjustable model method, consists in adapting to that system a mathematical model with an already fixed structure. The parameters of that model must be adjusted so that its dynamic behavior becomes very close to the system.

2.1 Entry-exit models

The description of the systems by the mathematical model entry-exit or black box is necessary for the nonlinear systems. The group of that system can be defined by a mathematical model entry-exit of the following kind:

$$A(q^{-1})y(k)=B(q^{-1})u(k)+w(k) \tag{1.1}$$

Where y(k) and u(k) are respectively the exit and the entry of the system at the discreet instant k, w(k) represents the noise (group of aleatory disturbances) that can act our system, and $A(q^{-1})$ and $B(q^{-1})$ are the polynomials respectively defined by :

$$A(q^{-1})= 1+a_1q^{-1} +\ldots+a_{nA}q^{-nA} \tag{1.2}$$

$$B(q^{-1})=1+b_1q^{-1} +\ldots+b_{nB}q^{-nB} \tag{1.3}$$

nA and nB being respectively the polynomials orders $A(q^{-1})$ and $B(q^{-1})$.

Different types of mathematic models letting describe the whole « system –noise » are proposed in literature [1] and [2]. Moreover the mathematic model structure depends mainly on the characteristics, influencing the system, and on its future use in an application.

We distinguish four mathematic models of entry- exit type which are very often used for the system description in order to formulate identification or order. The mathematic models structure is the one represented in (1.1) in which the noise w(k) can be defined in different aspects.

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Model 1

Here, we suppose that the correlated noise can be described by a moving average model (MA). The resulting mathematic model is of the ARMAX kind (Autoregressive with Adjusted average and exogenous entry). It can be defined by:

$$A(q^{-1})y(k)=B(k)u(k) +C(q^{-1})\, e(k) \qquad (1.4)$$

In which $C(q^{-1})$ is a Monique polynomial given by :

$C(q^{-1})= 1 +c_1q^{-1}+\ldots+C_{nC}q^{-nC}$; where nC is being the polynomial order $C(q^{-1})$

Model 2

We suppose that, in this mathematic model, the correlated noise v(k) could be described by an autoregressive model Ar. The mathematic model

$$A(q^{-1})y(k)=B(q^{-1})u(k)+ 1/D(q^{-1})e(k) \qquad (1.5)$$

In which $D(q^{-1})$ is a Monique polynomial such as :

$$D(q^{-1})= 1 +d_1q^{-1}+\ldots+d_{nD}q^{-nD} \qquad (1.6)$$

nD being the polynomial order $D(q^{-1})$

Model 3

In this mathematic model, we suppose that the noise acting on the system is correlated:

$A(q-^{1})y(q)=B(q)u(k)+v(k)$(1.7) in which {v(q)} is a correlated aleatory variables' sequence.

Model 4

This mathematic model of entry-exit type (1.1) can be defined by:

$$A(q^{-1})\, y(k)=B(q^{-1})u(k)+e(k) \qquad (1.8)$$

In which we suppose that the noise e(k) acting on the system is constituted of a sequence of independent aleatory variables of nil average and finished variance.

3. Deterministic identification

The parameter identification of the deterministic system or lightly noisy can be described by the entry-exit of the mathematic models (1.8).

In that this case, the noise level e(k) acting on the system is supposed weak so that he it doesn't influence a lot the identification quality and that the use of a deterministic allows us to give satisfactory results.

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3.1 Ordinary least square methods

(Let us) consider a system able to be described by an entry-exit model (1.8):

$$Y(k)=a_1y(k-1).....a_ny(k-n)+....+b_nu(k-n)+e(k) \quad (1.9)$$

In which a_i and b_j, i=j=1…n are unknown parameters. The degree n is supposed to be already known. The mathematic model can be written as follow:

$$y(k)=\phi^T(k)\hat{\theta}\,(k) + E\,(k,\hat{\theta}) \quad (1.10)$$

With $Ø^T$: observation vector

Θ(k) : unknown parameter vector

E(k,Θ) : modeling error

The identification method consists in determining the best estimated Θ from the knowledge of the observation vector. The least square method consists in minimizing the following quadratic criterion:

$$J(k, \Theta)=E^T(k, \Theta)\, E(k, \Theta) \quad (1.11)$$

With:

$$E\,(k, \Theta) =Y(k)- \phi^T(k)\;\; \Theta(k) \quad (1.12)$$

In which $$Y(k)=[y(1),\ldots,y(k)]^t \quad (1.13)$$

$$\Phi(k)=[\Phi(1),\ldots, \Phi(k)]^t \quad (1.14)$$

The estimated $\hat{\theta}(k)$of Θ is obtained from the minimization of the quadratic criterion.

By annulling the partial derived of J(k,Θ) according to Θ we get :

$$\hat{\theta}(k)=[\phi^T(k)\;\; \Theta(k)\;]^{-1}\phi^T(k)Y(k) \quad (1.15)$$

The estimator calculation $\widehat{\Theta}(k)$ needs the matrix inversion $[Ø^T(k)\; Ø(k)]$.

The least square method allows us to calculate $\hat{\theta}(k)$ from $\hat{\theta}(k-1)$ and so, avoid the matrix inversion. By putting the matrix Y(k) and Ø(k) under the form :

$$Y(k) = [Y(k-1\,)y(k)]^{T,}\; Ø(k)=[Ø(k-1)\; Ø(k)]^T$$

The estimator $\hat{\theta}(k)$ becomes then:

$$\hat{\theta}(k)=[Ø^T\,(k-1)\;\;\; Ø(k-1)+ \phi(k)\;\; \phi^T(k)\;\;]^{-1}[Ø^T(k-1)\; Y(k-1)+\phi(k)y(k)] \quad (1.16)$$

The use of the matrix lemma of inversion:

$$[A^{-1}+BC^{-1}B^T]^{-1}=A-AB[C+B^TAB]^{-1}B^TA \quad (1.17)$$

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In the expression:

$[Ø^T (k-1) \;\; Ø (k-1) +\phi(k)\, \phi^T (k)]^{-1}$ gives:

$\Theta(k)=[Ø^T(k-1) \;\; Ø(k-1)]^{-1}-[Ø^T(k-1) \;\; Ø(k-1]^{-1}\phi(k)[1+\phi^T(k)[Ø^T(k-1) \;\; Ø(k-1)]^{-1}\phi(k)]^{-1}].$

$\phi^T(k)[Ø^T(k-1) \;\; Ø(k-1)]^{-1}[Ø^T(k-1)\, Y(k-1)+\phi(k)y(k)]$ (1.18)

According to the expression : $\Theta\, (k-1)=[Ø^T(k-1) \;\; Ø(k-1)]^{-1}Ø^T(k-1)\, Y(k-1)$ the development of the $\hat{\theta}(k)$ expression leads to :

$\hat{\theta}(k)=\hat{\theta}(k -1)+([Ø^T(k-1) \;\; Ø(k-1)]^{-1}\phi(k)\, (y(k)-\phi^T(k)\hat{\theta}(k -1))/[1+\phi^T(k)[Ø^T(k-1) \;\; Ø(k-1)]^{-1}\phi(k)$ (1.19)

The matrix inversion $[Ø^T(k-1)\, Ø(k-1)]$ is replaced by a recurring algorithm :

$\hat{\theta}(k) =\hat{\theta}(k -1)+G(k)(y(k)-\phi^T(k)\hat{\theta}(k -1)$ (1.20)

In which:

$\hat{\theta}(k-1)$is the preciding value of unknown.

$\mathcal{E}(k)$ is the error that we would make at the umpteenth experiment if we took as a value of Θ the estimated one from the previous umpteenth experiments :

$\mathcal{E}(k)=y(k)-\phi^T(k)\hat{\theta}(k -1)$ (1.21)

G(k) is the necessary gain correction to move $\hat{\theta}(k-1)$to $\hat{\theta}(k)$ and has the expression :

$G(k)=[Ø^T(k-1) \;\; Ø(k-1)]^{-1}\phi(k)/[1+\phi^T(k)[Ø^T(k-1) \;\; Ø(k-1)]^{-1}\phi(k)]$ (1.22)

In setting: $p(k-1)=[Ø^T(k-1) \;\; Ø(k-1)]^{-1}$

The matrix P(k) will be equal to :

$P(k)=p(k-1)-p(k-1)\phi(k)\phi^T(k)p(k-1)/[1+\phi^T(k)p(k-1)\phi(k)]$ (1.23)

The algorithm of recursive estimate to the sense of the least squares is then presented under the form:

3. 2. From the measures at the moment k:

$G(k)=p(k-1)\phi(k)/[1+\phi^T(k)p(k-1)\phi(k)]$ (1.24)

$\mathcal{E}(k)=y(k)-\phi^T(k)\hat{\theta}(k -1)$

4. Equipment and methods.

We placed on a plot of land of 540 m^2 the irrigation equipment composed of a main pipe. At the end of that we placed a big sand filter containing a CPAZC pressure meter in bars of ± 0.1. On the second part of the latter we place a second small filter and following it a flow meter.

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DBM 610 in liter / hour. A second pipe received the water from the first pipe to which are attached pipes of smaller diameter. At the level of the last dropper, we place a lead calibrated in % at 10 cm depth and near the tomato plant at the extreme and of the plant's row. From that setting and in nearly a minute, we register the pressure ps, the flow ds and the relative humidity hs at the level of tomato plant. We set the plant water need at 40± 5%. Thanks to the toolbox «ident » under Matlab and by using the entry measures ps and ds the exit measures hs, we obtain the adequate model.

5. Results

With that box help we choose the model oe among others which are not close to the real model.

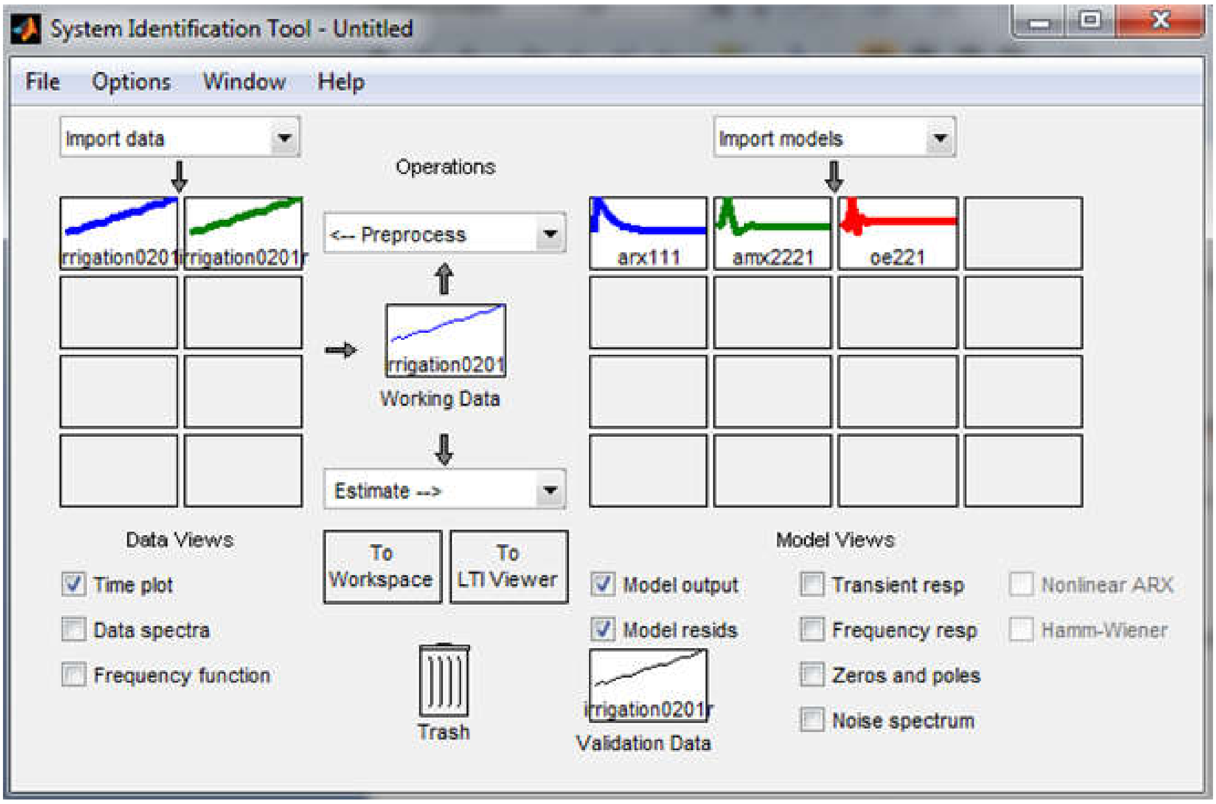

Fig.1: The Graphic user interface

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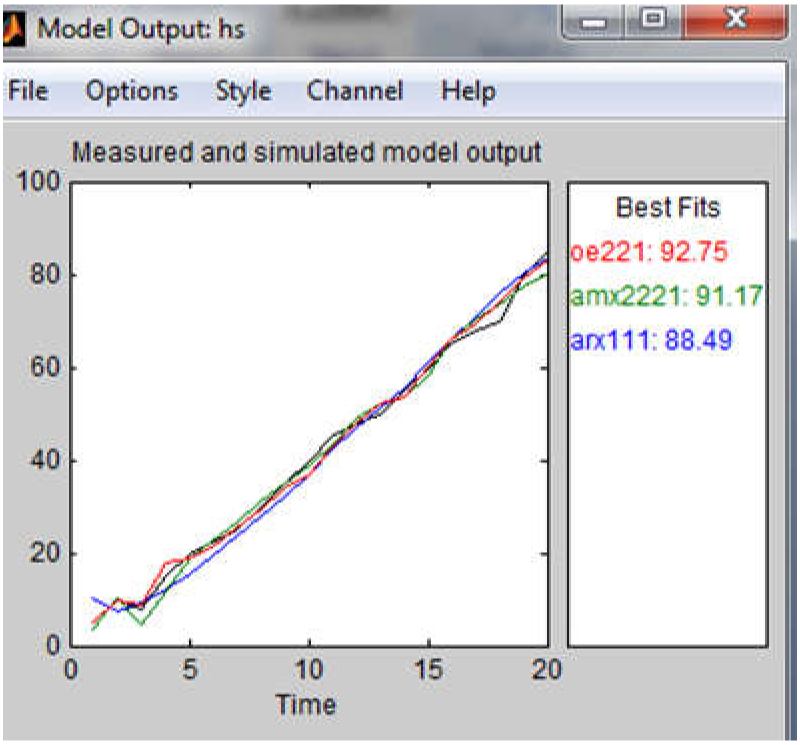

Fig.2: The Measured and simulated model output

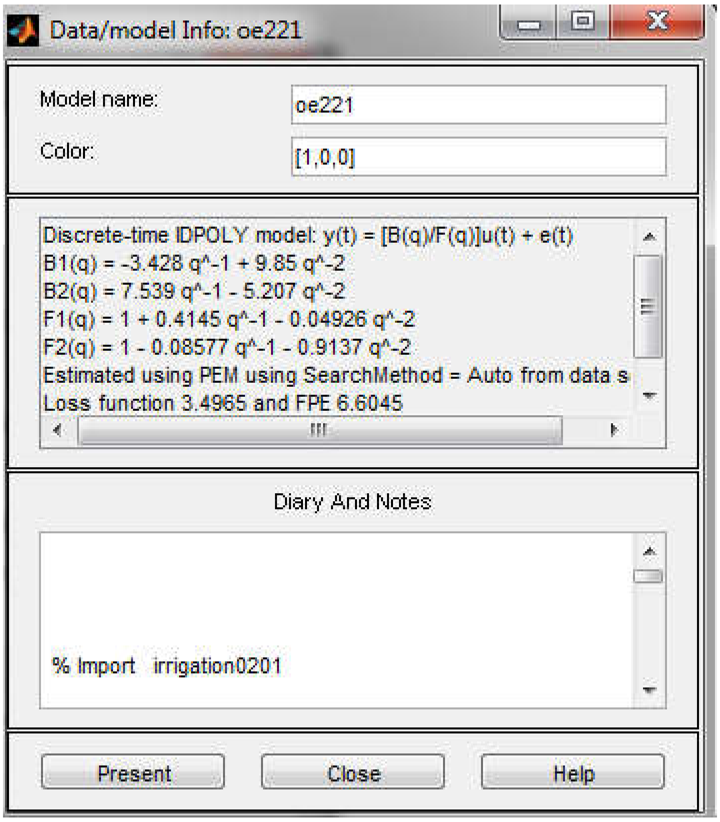

Fig.3: The parameters of the chosen model

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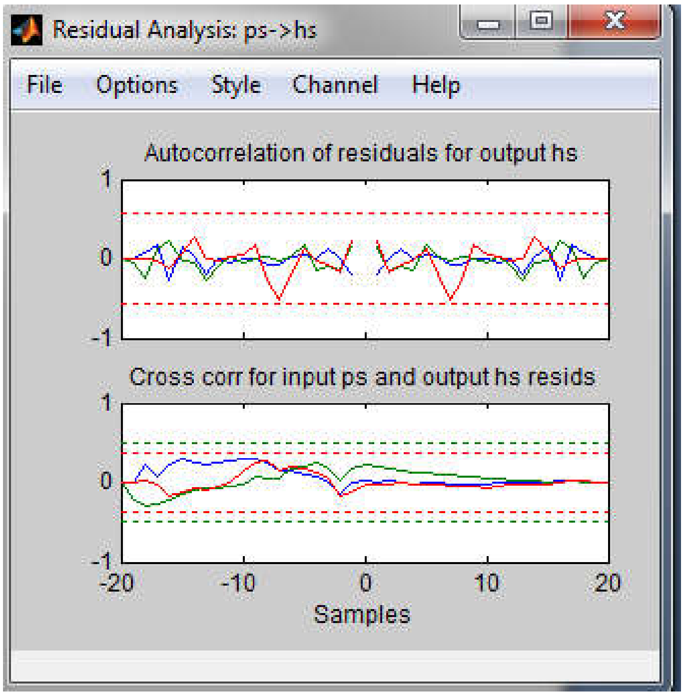

Fig.4: The Residual models analysis

6. Results and interpretation

The use of toolbox, fig.1 or interface graphic has enabled us to choose the model which is the nearest to the real system at 92.75 %, in our case. That model based on the exit error has as components:

$B_1(q)=-3,428q^{-1} +9,85q^{-2}$

$B_2(q)=7,539q^{-1} -5,207q^{-2}$

$F_1(q)=1+0,4145q^{-1} -0,04926q^{-2}$

$F_2(q)=1-0,08577q^{-1} -0,9137q^{-2}$

And the mathematic relation we are looking for to connect the exit to the two entries is the following:

$$hs(k)=[B_1(q)/F_1(q) + B_2(q)/F_2(q)]\ (ps(k)+ds(k))+e(k)$$

With hs soil relative humidity, ps the pressure, ds the water flow, e(k) the exit error while $B_1(q)$, $B_2(q)$, $F_1(q)$ and $F_2(q)$ are the polynomials of the model.

Fig .4 shows that correlation coefficient between the irrigation system exit and its two entries are close to zero. That coefficient proves the system is strongly nonlinear. That justifies the choice to go through the « black box » system. The independence test shows the correlation absence between the residues and the entries. These tests show that the chosen model is good to use. By validating our measures and our model, the error between the real model and the estimated one is 7.5%, Error that we evaluate as acceptable.

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The model precision is not demanded whereas stability is. After air cleaning of the irrigation system, the latter stabilizes and the undesired effects are enlightened little by little. This is justified by the use of LTI in the tool box « ident » in which all the models tend towards constants, particularly the chosen model.

Conclusion

The irrigation system is strongly nonlinear. The lack of mathematic relation linking the pressure, the water flow and soil humidity complicate the system order. By adding to these three factors the load loss, the irrigation equipment geometry, (elbow, angle, reflecting, length…) the ageing and the cost of that equipment, the problem solving becomes more and more difficult. As farmers, we meet these difficulties at every irrigation moment (water leak, equipment damage due to pipe problems). In this research, we considered the « black box » system. We only measured the pressure ps, the flow ds and the soil humidity and neglected the factors of disturbance. In this entry – exit system the measures are chosen to avoid the extreme cases, that is to say the pressure that goes over 5.5 bars and the nil one. Thanks to this research, we found a relation that links the exit hs to the two entries ps and ds as follow: $hs(k) = H(q)[ps(k) + ds(k)] + e(k)$ in which e(k) is an error. $H(q)=[B_1(q)/F_1(q) + B_2(q)/F_2(q)]$.

The system is orderable and stable too (lack of water leak and the burst of toric joints and decreasing of load loss …). The water distribution is even at the level of every dropper. The precision is not demanded in this system. Actually, the tomato plant need is chosen to avoid the dry state and the humid one at 100% (dry soil or 100% humidity).

This method enabled us to fight against the plant death by drought and asphyxiation that result from water stagnation. Thanks to this research, we could, on the one hand, decrease the production cost by avoiding the overuse of water, and on the other hand fight against many diseases in particular the « mildiou » that results from water evaporation and temperature increase in a tomato greenhouse. Very soon, we will apply the fuzzy regulation to that irrigation system. The latter fits better to the plant needs. In the most of the studies we use the « all or nothing » technology, while the plant can be satisfied by a water need situated between « all and nothing ».

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