Fuzzy Control of a Water Pump for an Agricultural Plant Growth System

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Abstract: At the present time there is a high pressure toward the improvement of all the production processes. Those improvements can be sensed in several directions in particular those that involve energy efficiency. The definition of tight energy efficiency improvement policies is transversal to several operational areas ranging from industry to public services. As can be expected, agricultural processes are not immune to this tendency. This statement takes more severe contours when dealing with indoor productions where it is required to artificially control the climate inside the building or a partial growing zone. Regarding the latter, this paper presents an innovative system that improves energy efficiency of a trees growing platform. This new system requires the control of both a water pump and a gas heating system based on information provided by an array of sensors. In order to do this, a multi-input, multi-output regulator was implemented by means of a Fuzzy logic control strategy. Presented results show that it is possible to simultaneously keep track of the desired growing temperature set-point while maintaining actuators stress within an acceptable range.

1 INTRODUCTION

Nowadays, in order to increase the companies competitiveness, all the production processes are subject to rigorous audits. The output of such studies lead to changes in several key variables that will, ultimately, lead to a performance increase. Those changes can happen at several levels, ranging from plant layout, tasks scheduling, rework or scrap minimization and, of course, energy efficiency.

Energy efficiency is a pressing problem that is addressed at several levels. In particular, at the European Union, there are currently several political mechanisms undergoing in order to both reduce the energy consumption and also to promote renewable-based energy production systems (Armstrong and Blundell, 2007).

However economic growth is tightly connected to energy consumption. Hence, in order to cope with all those constraints one must be able to find alternative strategies to devise more energy efficient production methods that will not scale up with the required economic development.

As can be expected, agricultural processes are not immune to this tendency. Within a global market paradigm, the costs reduction while maintaining the products quality, is a constant grower concern. Hence maintaining market competitiveness can then be a challenge tackled at both operational and technological fronts.

Regarding the latter, often it is possible to transpose solutions used in different contexts to alternative application bringing value to a new process. For example the water heating systems, based on thermodynamic pumps used in domestic applications, can be also used in agricultural processes as is the case of greenhouses productions.

This paper deals with a new devised strategy to improve the energy efficiency of a tree nursing station. This new solution replaces the actual resistor based heating system by an alternative using circulation of hot water in a closed pipe circuit. The water recirculation is performed by an electric pump and the heating is taken from the environment by means of a set of thermodynamic panels.

However, prior to the effective implementation of this solution, it is required to test if this alternative heating system can, in fact, be used to replace the old one. In order to do this a scaled version of a growing platform was built where the thermodynamic heating system was replaced by a butane gas water heater.

Both water pump and gas heating system must be

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controlled taking into consideration the imposed temperature set-point while maintaining system integrity. The actuators state will be function of exogenous information provided by an array of sensors and the control law. In this work a Fuzzy controller strategy was pursued due mainly to the fact that, under this paradigm, a expert type controller is easily translated to a Fuzzy behaviour system (Kia et al., 2009).

The remain of this paper will be divided into four additional sections. After a more thorough presentation of the addressed problem at section 2 the Fuzzy controller design strategy will be described along section 3. The obtained results, regarding both set-point tracking and actuator wearing, will be presented at section 4. Finally some concluding remarks, as long as future work trends, will be presented in section 5.

2 PROBLEM DESCRIPTION

In this section the addressed problem will be discussed in further deep. In order to do that some previous contextualization about the actual installed trees growing system will be provided. This system consists on platforms with around six meters of length and near two meters width placed inside a greenhouse where the air temperature is roughly controlled. In particular, the inside air temperature ranges, in average, from 10 to 30 degrees centigrade.

At the present time the installed growing machine is used to nurse olive trees and chestnuts, among others, until they are sufficiently resistant to be planted outdoors (Jacobs et al., 2009). The system is a tray, covered with perlite, and with an electric resistance coil format, powering 3 kW, running along the covered area. Actually the greenhouse has 9 growing stands leading to an installed power of near 30 kW. A picture of the above referred growing platform system is depicted in Figure 1.

During the winter time, when the indoor temperatures are lower, the average energy spent in each growing platforms is, in average, around 60 kWh per day. This number is excessive and import high production costs. In order to reduce this value an alternative heating system was devised by replacing the inefficient resistance based heating element by an water heating system drive by thermodynamic panels (Yang et al., 2007) (Huiling and Xiangzhao, 2012).

The heating process is straightforward as can be exemplified in the diagram of Figure 2.

Before implementing this heating system, and since the heat and flow requirements of the growing stand, under nominal and extreme conditions, is unknown, a scale prototype was built. First the stand

Figure 1: The currently installed growing platform inside the greenhouse. The center pipes are for irrigation purposes.

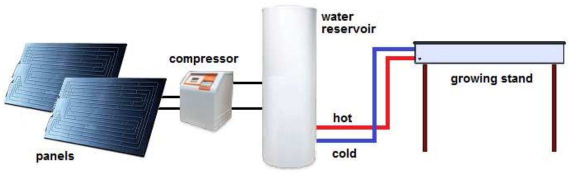

Figure 2: Block diagram of the growing stand heating system.

was implemented using the same structure material as the original. Only its dimensions was scaled to a platform of 125 cm $\times$ 65 cm. The height of 18 cm was deliberately let equal to the original in order for the solution devised for the prototype to be easily integrated thereafter in the real system.

The piping system was embedded in a special modelled styrofoam as shown in Figure 3. Then this assembly was placed inside the metal frame and filled with perlite.

In the test rig developed, the thermodynamic heating system was replaced by a butane gas heating. This operating change was mainly due to controllability and logistics. Nevertheless, the information one seeks to find could be also easily obtained by this new approach. Figure 4 shows an image of this alternative structure.

Moreover an array of sensors was dispersed along the system in several key points. Six waterproof temperature sensors (DS18B20) were distributed along the perlite surface. This set of sensors allows to analyse how well and uniform the heat spreads along the working area. In addition other temperature sensors are available: one to measure the heater outlet water temperature, the water temperature at a reservoir and the environment air temperature. The water flow is also measured by means of a flow sensor.

The water is made circulating by means of a 1/2 HP water pump system as can be observed from Fig-

Figure 3: The growing stand internal piping system meander around a piece of styrofoam used in radiant floors domestic heating systems.

Figure 4: Distribution of the temperature sensors along the perlite.

ure 5. The water pump is connected to the gas heater system by means of 1 inch pipes. On the other hand, the heater outlet pipe feeds the growing table. The circuit is closed by means of a return pipe from the table to the reservoir.

The control and data acquisition system was built around an Arduino Uno R3.0 (Dhamakale and Patil, 2011). Most temperature sensors connects to the microcontroller board by means of One-Wire communication protocol. Others require the use of an analog to digital (A/D) input. The time is kept tracked using a real-time clock (RTC) and data is locally saved in a secure digital (SD) memory card. The former is connected to the Arduino platform by means of inter-integrated circuit communication protocol (I^2C) and the latter by serial peripheral interface (SPI). This hardware setup can be observed from Figure 6.

The trees nursing process requires that the surface

Figure 5: Detail on the water circulating system. Below the table it is possible to observe both the water pump and the reservoir.

Figure 6: Control and data acquisition hardware built around an Arduino Uno board.

temperature be maintained around 23 degrees centigrade. In this process the main external disturbances are the indoor air temperature fluctuations and the load imposed by periodic irrigations. However, in this work, the latter is not considered.

In order to cope with the required surface temperature set-point two manipulated variables are available. The heater and the water pump states. Both have an important role in temperature regulation that will be further explained in the next section along with the control law devised to regulate this system.

3 THE FUZZY CONTROLLER

Besides set-point tracking, the addressed system also requires water temperature supervision in order to prevent the system collapse. Moreover, due to the actuators nature, a bang-bang approach to control must be performed. The use of an approximated first order system with low bandwidth, a classical approach to controller system design should not be a challenge. However, and in order to approximate de controller behaviour by an expert controller point-of-view, a Fuzzy based controller was devised (Dhamakale and Patil, 2011).

The controller design was carried out using the MATLAB®Fuzzy Logic Toolbox taking into consideration empirical knowledge. The controller structure, within the Fuzzy Toolbox context, can be observed from Figure 7.

This is a multi-input, multi-output controller system whose inputs are the average perlite surface temperature and the water temperature inside the reservoir. The output variables are the heater and water pump states.

The fuzzy inference mechanism selected was a Mamdani type (Mamdani and Assilian, 1975; Sakti, 2014). Moreover the conjunction and disjunction rules operation were the minimum and maximum respectively. The defuzzification process is carried out by means of a centroid operation over the feature space.

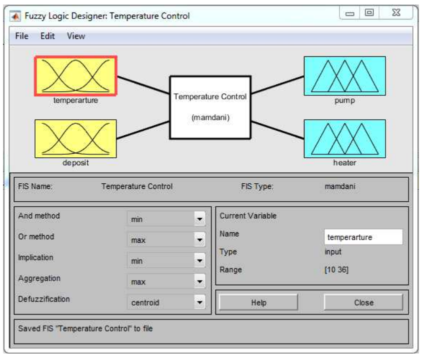

Figure 7: Overall Fuzzy controller structure and parametrization.

Regarding the surface temperature variable, the input space was partitioned into five Gaussian type Fuzzy sets. Each one was labelled as 'cold', 'cool', 'good', 'warm' and 'hot'. This fragmentation can be depicted from Figure 8.

Regarding the reservoir water temperature, the input space was divided into three sets labelled 'cold', "good' and 'hot'. The sets distribution along the input space range can be observed from Figure 9.

Now the output space for the water pump was split into three triangle type membership functions as can be concluded from Figure 10.

The same operation was carried out for the heater

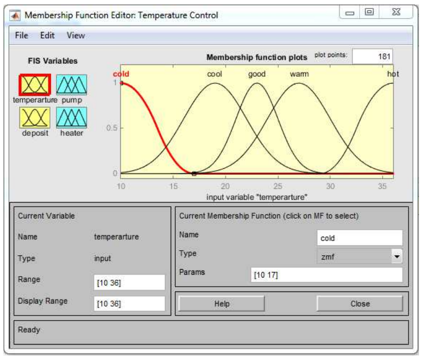

Figure 8: Surface temperature fuzzification. This input variable was differentiated into five partially overlapped sets.

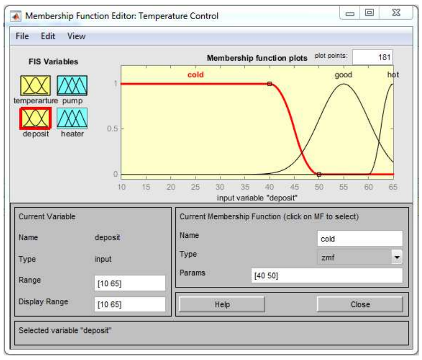

Figure 9: Reservoir water temperature fuzzification. Three sets was used to describe the water temperature status over the range from 10 to 65 degrees centigrade.

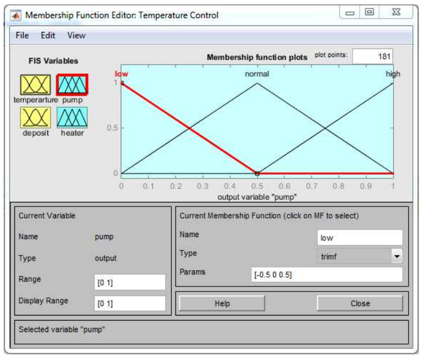

Figure 10: Output space partition for the water pump using three triangle type membership function.

variable. However, in this case, a five membership functions set was used to describe the output space. Nevertheless the same triangular shape membership functions were used as in the previous case as can be seen from Figure 11.

The Fuzzy controller rules were produced automatically by the MATLAB®software. In particular a total of 15 rules were produced. This rule based controller structure can be easily analysed by means

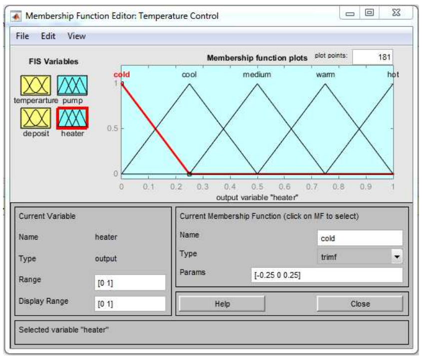

Figure 11: Output space partition for the gas heating system using five triangular shape membership functions.

of a graphical output available from the toolbox. A screenshot of this rule viewer graphical tool is presented in Figure 12.

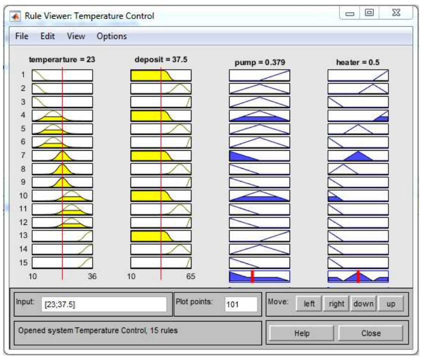

Figure 12: The rule viewer assuming an surface temperature of 23 degrees centigrade and a reservoir water temperature of 37.5 degrees centigrade.

In the next section the above designed Fuzzy controller behaviour will be presented. Its performance will be analysed regarding both set-point tracking and actuators stress. Even if the former figure of merit can be slightly relaxed the latter is of extreme importance in order to reduce wearing of both the water pump and the gas heating system by preventing high frequency switching states.

4 RESULTS AND DISCUSSION

Several tests were performed, always giving priority to the worst case scenario, with ambient temperatures close to 10 degrees centigrade. In all the performed tests the desired set-point temperature is considered constant and equal to 23 degrees centigrade. Below are presented the results of two tests. The first, whose results are illustrated in Figure 13, has a temperature starting point of around about 16 degrees centigrade.

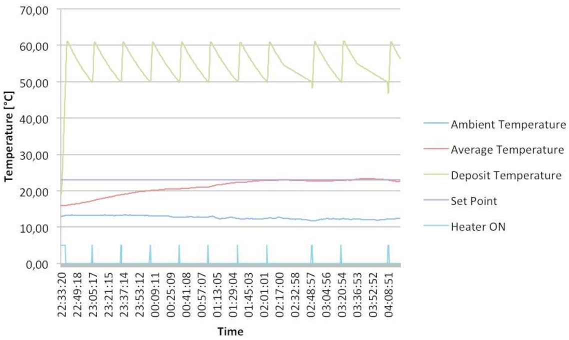

Figure 13: Results obtained during the first test. From top to bottom one can observe the following curves: Deposit temperature, set-point, average temperature, ambient temperature and heater status.

A second experiment, with lower water temperature starting point, was also performed. In this second case the initial system temperature is approximately 14 degrees centigrade and the average temperature environment stays around 11 degrees centigrade. The obtained results are presented on Figure 14.

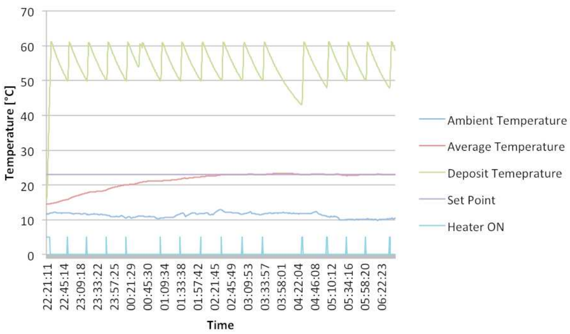

Figure 14: Results obtained during the second test. From top to bottom one can observe the following curves: Deposit temperature, set-point, average temperature, ambient temperature and heater status.

From both experiments it is possible to conclude that, in both cases, the controller was able to reach, and maintain, the set-point temperature. Moreover one can see that the closed loop system exhibits an over-damped response type. In addition it is possible to observe the heater state change during the operation. Notice that the water pump state did not change during the experiments and was always on. From the obtained data it is possible to conclude that the rate of change of the heater state has a period of around 30 minutes. Hence the designed controller did not lead to an aggressive closed loop response from the actuators point-of-view.

5 CONCLUSION

This paper addresses the implementation of a Fuzzy controller for a new tree nursing station heating system based on thermodynamic panels. This alternative strategy, if proven economically viable, will replace the older system whose heating system is based on electric heating elements. In order to infer the applicability of this technique a scaled test rig was built. This test rig was used to test if it was possible to attain the set-point temperature in the worst operating conditions and, if so, what will be the water temperature required and its mass flow. In the test rig the water was heated, not using the thermodynamic heating system, but a gas boiler whose state could be easily controlled and minimizing logistic problems. In addition, a half horse power water pump was installed, in order to make the water circulating. The pump operation was controlled by a simple on-off strategy.

In order to maintain the system state variables in the required range a multi-input, multi-output Fuzzy controller was designed. The controller input are the temperature information collected by an array of sensors and its output signal are the commands for both the water pump and the gas heater. The choice of this controller paradigm was due mainly to its simplicity and its proximity to empirical control based on expert knowledge.

From the obtained results it is possible to conclude that the designed controller was able to maintain the average surface temperature at the set-point level without generating any high frequency control signals. This is very important in order to reduce the wearing inherent to rapid on-off actuator state changes.

However further tests must be still performed using different operating conditions like increased air temperature, adding moisture to the perlite substrate since, in real operating conditions, the irrigation system periodically sprinkle the small trees. It is necessary to analyse how this change in thermal conductivity will be noticed in the overall system performance.

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