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Fuzzy Modeling Vapor Pressure Deficit to Monitoring Microclimate in Greenhouses ⋆

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Abstract
Instrumentation to measure microclimate in greenhouses is a task to developing before starting the identification and control moisture and temperature in greenhouses, a variable which best describe the microclimate and helps prevent fungus and disease risks, is the vapor pressure deficit (VPD), it is measured indirectly by means of two inputs: temperature and humidity, by means the psychrometric chart, and another way is using interpolation models. This paper shows methodology to measure VPD, by using fuzzy modeling type Takagi-Sugeno (T-S). Fuzzy modeling is based on expert and human knowledge, additionally this is combined with mathematical techniques to identify parameters of the antecedents and consequents of IF-THEN fuzzy rules, each IF-THEN fuzzy rule defines a submodel or region of interpolation. In this work, expert knowledge is the information described in psychrometric chart. Modeling learning was performed using air temperature and relative humidity, a set of 8 fuzzy rules was proposed to interpolate the VPD. The results of the fuzzy model are illustrated using measurements of an experimental greenhouse, and was contrasted with a model well known in the literature. The algorithm of fuzzy modelling VPD, was codified in two platform application real time: C to microcontroller and LabVIEW^{TM}, thus it is possible measuring the instantaneous VPD.

Keywords: fuzzy sensors, interpolation algorithms, microclimate monitoring.

1. INTRODUCTION

The microclimate modeling and control in greenhouses it has been done measuring temperature and relative humidity, in some studies, it is considered physically independent between them, this neglect causes problems in the study of greenhouse microclimate. The problems involved in controlling greenhouses are strongly dependent on the geographical area; solutions that are valid in some regions must be adapted or changed in order to fit others. Until now, many of the controllers designed for greenhouses have been associated with a single control variable, i.e. temperature, and this has given rise to monovariable controllers Herrero et al. (2007) and Fen (2010).

The VPD has been implemented successfully, in Zolnier et al. (2000) it was reported a basis theoretical for defining operational constraints necessary to develop VPD controller, that research was to determine operational constraints on equipment used for VPD control. In Vermeulen et al. (2012) is proposed automated leaf temperature monitoring of glasshouse tomato plants by using a leaf energy balance model, they measured VPD, it was determined by: H301 aspirated psychrometer Windspeed Ltd., Rhyl, Wales, UK., but these type sensor using the wet and dry bulb, a water reservoir and maintenance for over 7 days continuous. Unlike, in this work we use only two sensors: air temperature and relative humidity, embedded in a microcontroller, using interpolation algorithm fuzzy of the psychrometric chart. A methodology for irrigation control and nutrient supply was developed in Sigrimis et al. (2001), using common measurements of greenhouse climate, ambient and dry-bulb temperature, both measurements are converted to VPD using a virtual function from MACQU controller math library, it is not transparent the measurement of VPD if you not have the library. In Abdullah (2001), mean atmospheric vapor pressure deficit (AVPD) was used to develop a non stressed baseline equation and consequently the crop water stress index (CWSI), they computed instantaneous AVPD using the corresponding instantaneous wet and dry-bulb temperature and the standard psychrometer equation List (1971), Howell et al. (1986). The VPD is very important climate variable, increases nonlinearly with increase in temperature but decreases with increase in relative humidity, in

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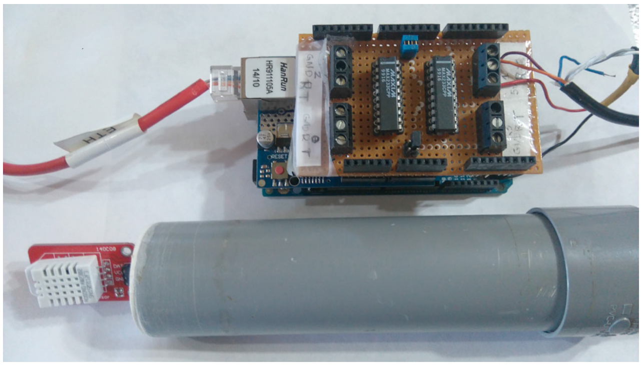

Figure 1. Prototype: Arduino's microcontrollers, ethernet shield, transceiver RS-232, sensor electronics DHT22 and housing of pvc.

Pahuja et al. (2015), was proposed a model greenhouse-crop vapor pressure deficit (GH-crop VPD) based multi-input multi-output fuzzy climate controller that operates in feedforward mode and regulates greenhouse climate conducive for healthy plant growth and yield. In that implementation of greenhouse climate control simulator, VPD is estimated using Arrhenius equation, see Prenger (2000). We propose here a fuzzy algorithm, it is inspired by Prenger (2000), the aim of this paper is to illustrate a new fuzzy interpolation model VPD.

Modelling and control microclimate in greenhouses, evapotranspiration modeling, plant water stress and control of irrigation cycles, they have been studied successfully with fuzzy logic techniques, see Lafont (2002), Salgado (2005), Trabelsi et al. (2007), Ramos et al. (2010), Hurtado et al. (2010) and Hahn (2011).

2. MATERIALS AND METHODS

For embedding the fuzzy VPD algorithm, we draw on a microcontroller ATmega328, by means serial communication (RS232) it transceiver with another ATmega2560 and link to ethernet Arduino shield. A sensor module DHT22 Digital-output relative humidity and temperature, operating range: humidity $0-100\%RH$; temperature $-40+80°$C, accuracy: humidity $\pm 2\%RH(Max \pm 5\%RH)$; temperature $< \pm 0.5°$C. C language compiler for Arduino 1.6.1 was used, which is free software. Microcontrollers network are connected to a central computer via Ethernet using software LabVIEW^{TM} 2014, for instance in this prototype, we used only one fuzzy VPD sensor, see Fig. 1 for an example.

It was interpolate 8 curves (relative humidity, temperature, vapor pressure) from psychrometric chart see Prenger (2000), 8 fourth-order polynomials was identified using MATLAB^{TM} function *polyfit(x,y,n)*, this polynomials are consequent of fuzzy IF-Then rules type T-S.

To learning parameters and the cross validation of the modeling fuzzy VPD, was selected experimental data files microclimate from December 19-29, 2015, to experimental greenhouse type *Richel* of The University of South Toulon Var- France. For data acquisition LabVIEW^{TM} 2014, it was developed a datalogger using VIs to acquired every 1 minute temperature air and relative humidity and consequently computed the VPD.

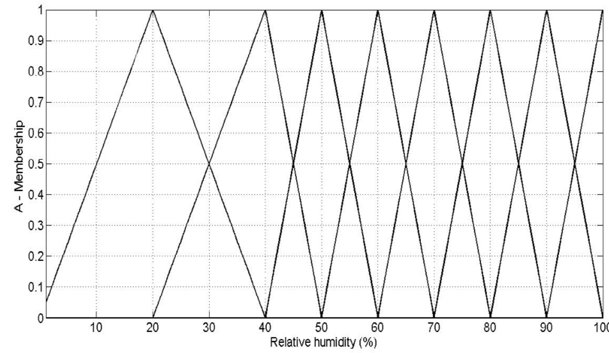

Figure 2. Set fuzzy: fuzzy partition of the relative humidity.

2.1 Fuzzy membership functions and rules

A static or dynamic system which makes use of fuzzy sets or fuzzy logic and of the corresponding mathematical framework is called a fuzzy system, see Babuška (1998). the modelling of fuzzy rules type T-S, applied in this paper is rule (1):

$$R^i : \textbf{If } RH(k) \textbf{ is } A^i \textbf{ Then } VP(k)^i = \theta^i \cdot powT(k)^T \quad (1)$$

where R^i is the i_{th} rule, $i = 1, 2, ..., 8$, RH is relative humidity, (k) instant of sample, A is a triangular membership function, see Fig. 2 fuzzy partition of relative humidity, θ is a vector of parameter or polynomial coefficients, and $powT$ is a transpose vector with powers of air temperature.

2.2 Parameter identification

We use 8 curves of $RH(\%)$ corresponding to the set $\{100, 90, 80, 70, 60, 50, 40, 20\}$, see Prenger (2000) is proposed a modified psychrometric chart, the horizontal and vertical axis are: air temperature and vapor pressure, respectively. It is mapped a membership by each polynomial of vapor pressure $(VP(T, HR))$. When the input RH, which does not correspond to the set learning curves $(\{100, 90, ..., 20\}$, thus interpolation is performed with the fuzzy aggregation of two submodels or polynomials. Parameters scalar a, b and c for the triangular memberships are shown in table 1, see definition of triangular membership in MATLAB^{TM} - *Fuzzy Logic Toolbox*. To identify the parameters of polynomials (θ^i), it was used $polyfit(T, VP, 4)$. In the table 2 are shows the coefficients, which take the form of equation (2), where $VP(k)$ is the air vapor pressure at instant (k).

$$VP(k)^i = a5^i \cdot T(k)^4 + a4^i \cdot T(k)^3 + a3^i \cdot T(k)^2 + a2^i \cdot T(k) + a1^i \quad (2)$$

2.3 Defuzzification and calculation of VPD

The center of gravity (COG) defuzzifier was codified, see equation (3), where $AVP(k)$ is the vapor pressure global or aggregation of rule outputs, each fuzzy rule is a submodel, $\mu_{A^i}(RH(k))$ is the $i-th$ membership function, computed at the input $RH(k)$. The vapor pressure deficit, is defined