HUMIDITY CONTROL OF AGRICULTURAL SOIL USING ANALOG MODELING

Rodica VARBAN¹, Diana MESAROS², Alexandru Marius SILAGHI², Tiberiu COLOSI³

¹Department of Crops Science, University of Agricultural Sciences and Veterinary Medicine, Calea Manastur nr. 3-5 Cluj-Napoca, Romania

E-mail: rodica.varban@usamvcluj.ro

²Control Systems Engineering Department, University of Oradea, Str. Universității nr. 1, Oradea, Romania

E-mail: dsas@uoradea.ro; masilaghi@uoradea.ro

³Automation Department, Technical University Cluj-Napoca, Str Memorandumului nr.28 Cluj-Napoca, Romania

Tiberiu.Colosi@aut.utcluj.ro

Abstract—This paper presents a simplified version of analog modeling for humidity of an agricultural soil, both isolated and included in a simple control scheme, being emphasized the application aspects for such a system. This article also includes preliminaries for agricultural soil model included in a simple humidity control scheme with some interpretation variants for evolution of processed signals for possible applications.

Keywords—Agricultural soil, exponential functions, simplified analog model, computer analog modeling, approximate solutions for second order partial differential equations with two variables

I. PRELIMINARIES IN ANALOG MODELING OF AGRICULTURAL SOIL

This paper aims to solve the control scheme presented in figure 1 having in its components the controller K_R the actuator K_V the negative reaction transducer K_N and the analogical model of the agricultural soil [1-4]:

$$y_{00}(t, s) = K_y \cdot F_{00}(t, s) \cdot u_0(t) \quad (1)$$

Fig. 1. Analog model for an agricultural soil included in a control scheme

The upper surface of agricultural soil in direct contact with the atmosphere, is considered a square with sides $L = 1m$, having the area $L \times l = 1m^2$ and the final depth on the abscissa (s) equal to $s_f = 1m$ resulting the volume of agricultural soil: $L^2 \cdot s_f = L^2 \cdot 1 = 1m^3$. [5-8]

The main goals of this paper are:

- Analog modeling of agricultural soil considered isolated $y_{00}(t, s) = K_y \cdot F_{00}(t, s) \cdot u_0$;
- Analog modeling of the entire equivalent system shown in Figure 1 in which agricultural soil is included in a simple humidity control scheme $y_{00}(t, s) \left[\frac{l}{m^3} \right]$
- Interpretation of humidity control performance $y_{00}(t, s)$ at different soil depths s_1, s_2, s_3 associated with possible positive results on botanical phenomena;

The analog modeling of the agricultural soil is represented by two exponential functions, one with increasing evolution

$F_{0T}(t)$ in relation to time (t) and one with decreasing evolution $F_{0S}(s)$ in relation to the depth of the soil (s) [1-4].

$$F_{0T}(t) = 1 - \frac{T_1}{T_1 - T_2} e^{-\left(\frac{t}{T_1}\right)} - \frac{T_2}{T_2 - T_1} e^{-\left(\frac{t}{T_2}\right)} \quad (2)$$

$$F_{0S}(s) = \frac{s_1}{s_1 - s_2} e^{-\left(\frac{s}{s_1}\right)} - \frac{s_2}{s_2 - s_1} e^{-\left(\frac{s}{s_2}\right)} \quad (3)$$

From relations (2) and (3) results the soil humidity dependent on time $t(hours)$ and depth $s(meters)$ for ($s_0 \leq s \leq s_f$) represented by the following equation [1-4]:

$$y_{00}(t, s) = K_y \cdot F_{0T}(t) \cdot F_{0S}(s) \cdot u_0(t) = F_{00}(t, s) \cdot u_0(t) \quad (4)$$

Where [5-7]:

- $u_0(t)$ represents the flow on the input surface expressed in $u_0 \left[\frac{l}{m^2 h} \right]$;

- the flow is coming directly either with precipitation or from a water pump included in the actuator K_V from figure 1.

The proportionality coefficient K_y has the following form[1,2]:

$$K_y = \frac{y_{00}[\frac{l}{m^3}]}{u_0[\frac{l}{m^2h}]} = [\frac{h}{m}] \quad (5)$$

The choice of time constants T_1, T_2 expressed in hours and the choice of space constants S_1, S_2 expressed in meters is made:

$$\lambda_T = \frac{T_2}{T_1} = (1,1 \sim 1,9) \quad (6)$$

$$\mu_T = \frac{t_f}{T_1 + T_2} \quad (7)$$

$$\lambda_S = \frac{S_2}{S_1} = (1,1 \sim 1,9) \quad (8)$$

$$\mu_S = \frac{s_f}{S_1 + S_2} \quad (9)$$

Note that the average values $\lambda \cong 1.5$ and $\mu \cong 4$ are not always common. For the presented case, the final values for time t_f are expressed in hours or tens of hours, and for the final depth s_f is considered 1m.

Fig. 2. Analog model for an agricultural soil - humidity propagation in soil depth

In a first stage, the following values are chosen:

- $T_1 = 0.08t_f$;
- $T_2 = 0.17t_f$;
- $S_1 = 0.08s_f$;
- $S_2 = 0.17s_f$

Inflection abscissas t_i and s_i are obtained from the condition of cancellation of second order derivatives [1-4]:

$$\bullet \frac{\partial^2 F_{0T}(t)}{\partial t^2}$$

$$\bullet \frac{\partial^2 F_{0S}(s)}{\partial s^2} = 0$$

As a result:

$$t_i = \frac{T_1 \cdot T_2}{T_2 - T_1} \ln \frac{T_2}{T_1} \quad (10)$$

$$s_i = \frac{S_1 \cdot S_2}{S_2 - S_1} \ln \frac{S_2}{S_1} \quad (11)$$

Finally:

$$t_i = \frac{0.17t_f \cdot 0.08t_f}{0.17t_f - 0.08t_f} \ln \frac{0.17t_f}{0.08t_f} = 0.01025t_f \quad (12)$$

$$s_i = \frac{0.17s_f \cdot 0.08s_f}{0.17s_f - 0.08s_f} \ln \frac{0.17s_f}{0.08s_f} = 0.01025s_f \quad (13)$$

The two dependencies of the inflection abscissas t_i and s_i with the final values t_f and s_f from (12) and (13) become particularly important in experimental representation of functions $F_{0T}(t)$ and $F_{0S}(s)$ from (2), (3) and (4) through three points.

As may be seen in figure 2, the flow on the inlet surface $u_0 \left[\frac{l}{m^2 h} \right]$ is considered the step for which the humidity $y_{00}(t, s_0)$ becomes the fastest increasing and the humidity $y_{00}(t, s_f)$ becomes the most attenuated increasing [1,2].

For $y_{00}(t_f, s)$ corresponds the exponentially decreasing humidity as the depth increases from s_0 to s_f . In relation to the two abscissas of inflection, t_i and s_i , are also defined the humidity $y_{00}(t_i, s_0)$ and humidity $y_{00}(t_f, s_i)$.

As a result, the simplified model obtained by experimental measurements falls between a signal $y_{00}(t, s) \left[\frac{l}{m^2 h} \right]$ representing the water flow on the input surface $u_0 \left[\frac{l}{m^2 h} \right]$ and the output signal $y_{00}(t, s) \left[\frac{l}{m^3} \right]$ representing the soil humidity.

The simplified model of agricultural soil can also be expressed by the following relation [1,2]:

$$y_{00}(t, s) = K_y \cdot \left(1 - \frac{T_1}{T_1 - T_2} e^{-\left(\frac{t}{T_1}\right)} - \frac{T_2}{T_2 - T_1} e^{-\left(\frac{t}{T_2}\right)} \right) \cdot \left(\frac{S_1}{S_1 - S_2} e^{-\left(\frac{s}{S_1}\right)} - \frac{S_2}{S_2 - S_1} e^{-\left(\frac{s}{S_2}\right)} \right) \cdot u_0(t) \quad (14)$$

Where:

- $u_0(t) \left[\frac{l}{m^2 h} \right]$ the flow on the inlet surface
- $y_{00}(t, s) \left[\frac{l}{m^3} \right]$ soil humidity
- $K_y = \left[\frac{h}{m} \right]$ the proportionality coefficient can be interpreted as the time expressed in hours necessary for inlet surface flow $u_0(t) \left[\frac{l}{m^2 h} \right]$ to ensure the humidity $y_{00}(t, s) \left[\frac{l}{m^3} \right]$ on the entire depth $s_f [m]$ of the soil

II. AGRICULTURAL SOIL MODELED USING COMPUTER

For many decades, automated processes from different fields of industry are widely described in literature in order to present the necessity of progress and evolution [5-9].

In order to compute the model of the isolated agricultural soil, the algorithm is implemented in Matlab environment. In the following, the pseudo-code algorithm is presented [1-2]:

TABLE I. THE OUTPUT RESULTS $y_{00}(t, s) \left[\frac{l}{m^3} \right]$ AFTER RUNNING THE PROGRAM

s \ t	0	1	2	3	4	5	6	7	8	9	10
0	0	2.05	4.90	6.97	8.26	9.02	9.45	9.69	9.82	9.90	9.95
0.1	0	1.63	3.89	5.54	6.56	7.16	7.50	7.69	7.80	7.86	7.90
0.2	0	1.048	2.499	3.553	4.210	4.595	4.815	4.939	5.000	5.046	5.068
0.3	0	0.622	1.484	2.118	2.508	2.728	2.859	2.933	2.937	2.996	3.010
0.4	0	0.357	0.851	1.210	1.434	1.566	1.641	1.683	1.706	1.719	1.727
0.5	0	0.201	0.480	0.683	0.810	0.884	0.926	0.950	0.963	0.971	0.975
0.6	0	0.113	0.269	0.382	0.453	0.495	0.519	0.532	0.539	0.543	0.546
0.7	0	0.063	0.1501	0.213	0.253	0.276	0.289	0.296	0.300	0.303	0.304
0.8	0	0.035	0.083	0.1188	0.1400	0.153	0.161	0.1651	0.1674	0.1687	0.1694

0.9	0	0.0194	0.0464	0.0660	0.078	0.085	0.0895	0.0918	0.0931	0.0938	0.0942
1	0	0.0108	0.0258	0.0367	0.0435	0.0497	0.0499	0.0510	0.0517	0.0521	0.0523

In table 1 are presented the output results after running algorithm. The humidity $y_{00}(t, s = 0)$ presents the fastest exponential increase from values 0 to 9.95 meanwhile the humidity $y_{00}(t, s_f = 1)$ presents negligible values increasing exponential evolutions from 0 to 0.0523.

Also, the humidity $y_{00}(t_f = 10, s)$ presents a very fast decrease from the value $y_{00}(t_f, s_0) = 9.95$ to the value $y_{00}(t_f, s_f) = 0.0523$

For intermediate values these exponential evolutions become progressively attenuated but still increasing for $y_{00}(t, s = \text{const})$ and decreasing for $y_{00}(t = \text{const}, s)$.

III. AGRICULTURAL SOIL INCLUDED IN A SIMPLE CONTROL SCHEME MODELED USING COMPUTER

Physics, Chemistry, Biology, Microbiology, Electrical machines, Electrochemical and Thermal are just a few fields of industries where analogical modeling methods are used. In these days, when interdisciplinary collaboration represents a must, modeling various types of processes represents a great step. Introducing control automation schemes in various emphasize a great level of innovation research and development [10-16].

The analog model of the agricultural soil presented in the previous chapter was included in a very simple control scheme which contains the controller (K_R), the actuator (K_V) and the transducer (K_N).

Due to the fact that these elements are electronic with negligible inertias with respect to time (T_1, T_2) and space (S_1, S_2) constants of higher values, these elements tend to be non-inertial.

As a result, transfer functions are no longer used for analog definition and modeling, but a simple system of algebraic relations such as [1-4]:

$$\begin{cases} y_{00} = K_Y \cdot F_{00} \cdot u_0 \\ u_0 = K_V \cdot c_0 \\ c_0 = K_R \cdot a_0 \\ a_0 = w_0 - n_0 \\ n_0 = K_N \cdot y_{00} \end{cases} \quad (15)$$

In the following it is presented the agricultural soil modeling algorithm included in a simple humidity control scheme $y_{00}(t, s) \left[\frac{l}{m^3} \right]$ in relation to the reference signal $w_0(t)$ [1-4]:

A controlled model (y_{00}) in relation to reference signal (w_0) after eliminating the reaction signal (n_0), deviation signal (a_0) command signal (c_0) and actuator signal (u_0) is obtained [1-4]:

$$y_{00} = \frac{K_R \cdot K_V \cdot K_Y \cdot F_{00}}{1 + K_R \cdot K_V \cdot K_Y \cdot F_{00} \cdot K_N} w_0 \quad (16)$$

In addition to previous chapter, the following notations are considered: $K_V = 1$, $K_N = 1$ and the proportionality coefficient $K_y = 1$. The following relation is considered for PID controller [1-4]:

$$K_R = K_P + K_I t + K_D e^{-\left(\frac{t}{T_D}\right)} \quad (17)$$

Where:

- K_P – proportional effect
- K_I – integrative effect in relation to time
- K_D – derivative effect in relation to time
- T_D – time constant

In the following table are presented the PID control performances ensured at different propagation depth:

TABLE II. PID CONTROL PERFORMANCES ENSURED AT DIFFERENT PROPAGATION DEPTH

$s[m]$	$s=0$	$s=0.25$	$s=0.5$	$s=0.75$	$s=1$
$u_0 \left[\frac{l}{m^2 h} \right]$	9.88	24.4	87.5	253	456
$y_{00} \left[\frac{l}{m^3} \right]$	98.35	95.93	85.4	57.6	23.9

Numerous evolutions of the signals u_0 and the output y_{00} in relation to multitude of parameters from a control scheme can be observed, including through a correlation of PID controller through the proportional integrative derivative effect.

IV. CONCLUSIONS

The analogical model of the agricultural soil is defined by input $u_0 \left[\frac{l}{m^2 h} \right]$ and the output $y_{00}(t, s) \left[\frac{l}{m^3} \right]$ represented by the algebraic form $y_{00} = K_y \cdot F_{00} \cdot u_0$.

In order to obtain accurate results it is necessary to ensure a realistic choice for K_y , u_0 , final values t_f, s_f from which to result the time constants T_1, T_2 and space constants S_1, S_2 , as close as possible to humidity properties of the soil in depth.

There is a variety of associated equipment that may be chosen for transducers, for PID electronic controllers and for the actuator, which may be represented by pumps easily included in control schemes.

An important step is the design and realization of a specialized micro-laboratory for the study of agricultural soils by knowing the phenomena associated between the specific study of humidity and the diversity of plants grown in certain soil humidity conditions.

Fractional Calculus is considered to be used for further development to obtain improved performances of PID

controllers using the fractional order derivatives and integrals [7-9].

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