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FUZZY MODELING OF SOLAR RADIATION ON SURFACES WITH DIFFERENT EXPOSITIONS AND DECLIVITY

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Abstract- **This paper presents a study on the application of fuzzy logic modeling of solar radiation on surfaces, proposing an intelligent expert system as an alternative to mathematical model. Data were obtained from a study conducted in the Department of Rural Engineering of UNESP, Jaboticabal - SP (Brazil), from March 2002 to March 2003, in which conducted the evaluation of a mathematical model to estimate solar radiation incident. With the study of radiation levels applied to ANFIS tool (Adaptive Network-based Fuzzy Inference System) 3 membership functions and 250 epochs, obtaining an approximate fuzzy model of solar radiation as a function of a single variable, the date of year.**

Keyrowlds– **Solar Radiation, ANFIS, Fuzzy, approximation model, irregular surfaces**

I. INTRODUCTION

In the agricultural sector the knowledge of solar irradiance on non-horizontal surfaces is of great importance. Surfaces with different exposures and slopes are subject to different total solar radiation [4].

The measurement of solar irradiance on surfaces with different exposures and slopes is not feasible in many situations due to the high cost of the sensors. One solution is the development of mathematical models to estimate, from determinations horizontal surface irradiance on land with different exposures and steepness [4].

According to Turkish and Rizzatti (2006), a mathematical model widely used to estimate the global solar radiation on surfaces with exhibitions and slopes from horizontal determination, is the Kondratyev (1977).

Already for a model of the irradiance only by means of measurements and the dates from the same used the method ANFIS (Adaptive Network-based Fuzzy Inference System).

Objective of this work is by ANFIS method, performing the modeling of global radiation on a surface by means of a study measuring data, allowing the obtaining of radiation by means of simple functions and fewer variables.

II. MATHEMATICAL MODEL

The model Kondratyev (1977) calculates the solar radiation on a surface with a slope specifies, from the radiation measured horizontally. This model describes the direct solar radiation flux on an inclined surface with arbitrary orientation (Ss) can be expressed by means of the radiation flux received by a surface normal (SH) to solar radiation, also presents the equation (1):

$$S_s = \frac{S_H}{sinh}(A1 + B1cos\Omega + C1sin\Omega) \quad (1)$$

In that,

$A1 = cos\alpha sin\phi sin\delta + sin\alpha[cos\psi_n(tan\varphi sin\phi sin\delta - sin\delta sec\varphi)]$;

$B1 = cos\alpha cos\phi cos\delta + sin\alpha cos\psi_n sin\phi cos\delta$;

$C1 = sin\alpha cos\delta sin\psi_n$;

$sinh = sin\phi sin\delta + cos\phi cos\delta cos\Omega$;

Ω – Sun hour angle at a given time;

α – Angle of the ramp to the horizontal;

ϕ – Latitude of the location;

δ – Solar declination, and

ψ_n –Azimuth of the normal ramp projection.

III. FUZZY MODEL

One of the characteristics of fuzzy systems that enable many of its applications in modeling of complex processes, pattern recognition, control systems, among others, is the capacity to approach. It is known that the fuzzy systems are universal function approximators [4][5]. For the construction of sets of fuzzy rules and membership functions it was used the ANFIS method. A ANFIS is a fuzzy inference system (FIS) whose parameters are adjusted by an adaptive neural network [1].

The ANFIS was implemented through the training data, consisting of the measurement date (independent variable) and the solar radiation (dependent variable) measured on a plate with 20% slope and north exposure (20N), obtained in the work of Turkish and Rizzatti (2006).

The initial FIS was generated, Sugeno type, with the training data and was implemented three membership functions of the trapezoidal type.

With the FIS generated, held training via ANFIS 250 epochs obtaining the parameters of the three trapezoidal membership functions and from three rules.

IV. TURKISH AND RIZZATTI (2006) WORK DATA

The study was conducted with data from a survey by the Department of Rural Engineering of UNESP located 21º15'22 " south latitude 48º18'58 " west longitude and altitude of 575 m with a climate Cwa. In the survey of Turkish and Rizzatti (2006) were utilized surfaces with an area of 10.5 m² with different slope characteristics, and the work addressed the survey with 20% slope and north exposure (20N). In the research conducted also radiation measurements for each surface, with the horizontal (H) used to estimate the radiation on other surfaces of the Kondratyev model (1977).
Table 1 presents data measured solar radiation (RSM) and calculated solar radiation (RSC) obtained by the work of Turkish and Rizzatti (2006). Being the RSC obtained through the Kondratyev model (1977) to the surface 20N fall winter period.

V. RESULTS

With table 1 was obtained training data of ANFIS system, with variable dependent RSM and the independent variable to date, so that it was inserted according to their order in the year, for example, February 15 is the day 46 of the year.

Was held training via ANFIS, 250 epochs, obtaining

the membership functions A1, A2 and A3 adjusted according to Figure 1 and the rules of the fuzzy model (2). It is observed that the training was carried out 250 epochs, because training with a higher amount of epochs did not result in a considerable increase in the correlation, as shown in Table 2.

r1: IF X1 = A1 THEN y1 = 0,3114X1 + 539,5;

r2: IF X1 = A2 THEN y2 = 2,055X1 + 78,61; (2)

r3: IF X1 = A3 THEN y3 = 5,628X1 – 785,3.

Table 2 - Correlation depending on the number of epochs.

Number of epochs	Correlation
100	0,7819
200	0,8600
250	0,8894
300	0,8898
400	0,8898

The result of fuzzy modeling is shown in Figure 2, where it is observed the ability of the fuzzy system to bring the radiation data for a model with only one input variable and three polynomial functions.

Table 1 – solar radiation measurement (RSM) and calculated (RSC) (Turco; Rizzatti, 2006).

Date	RSM (cal/cm².day)	RSC (cal/cm².day)	Date	RSM (cal/cm².day)	RSC (cal/cm².day)
03/04/2002	567,1499	547,7489	28/06/2002	436,1173	440,2453
12/04/2002	554,0302	533,2241	01/07/2002	430,8205	436,8551
19/04/2002	542,8075	517,4186	02/07/2002	442,1078	447,6101
23/04/2002	539,951	513,2299	08/07/2002	491,6955	496,836
28/04/2002	517,9594	492,3747	14/07/2002	466,9433	471,0111
10/05/2002	479,976	483,3855	15/07/2002	466,6168	470,0044
24/05/2002	490,3397	492,4595	16/07/2002	447,2283	460,6987
25/05/2002	502,8575	502,9728	17/07/2002	442,0692	447,6276
26/05/2002	496,6234	497,5481	18/07/2002	406,601	421,6346
27/05/2002	494,7806	498,3543	24/07/2002	480,1602	482,9818
28/05/2002	481,504	481,7289	25/07/2002	484,3378	488,524
02/06/2002	440,3214	447,3963	26/07/2002	487,7262	490,9732
03/06/2002	458,0108	461,4575	28/07/2002	478,0524	483,044
04/06/2002	460,6637	463,9741	08/08/2002	472,0764	479,2292
05/06/2002	458,678	464,1144	15/08/2002	461,5509	467,347
06/06/2002	382,2497	403,4671	16/08/2002	487,8011	492,9303
07/06/2002	450,1924	456,7992	17/08/2002	501,0865	501,0865
08/06/2002	442,5398	448,3798	18/08/2002	530,6882	533,1727
14/06/2002	434,5882	439,437	19/08/2002	536,2503	537,5357
15/06/2002	426,0747	433,1568	02/09/2002	599,1741	606,1592
27/06/2002	445,9111	455,9137	03/09/2002	577,3814	581,9539

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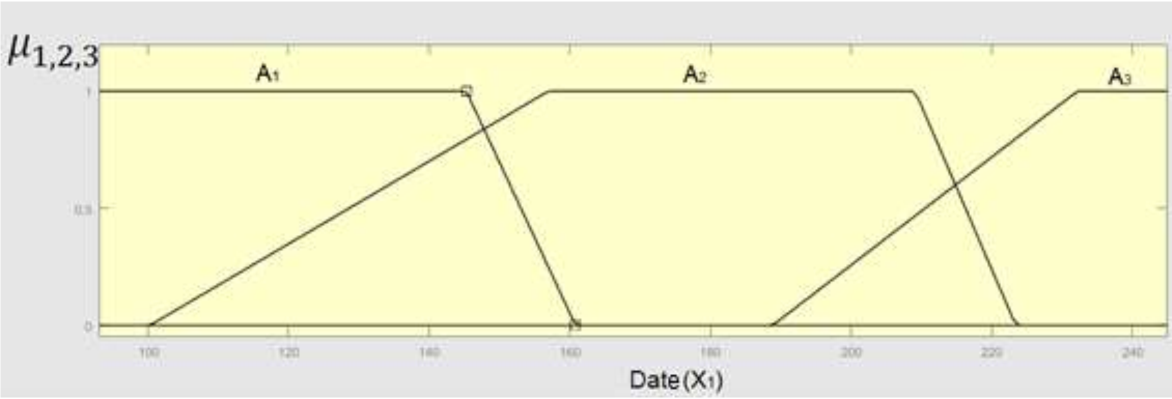

Figure 1 - membership functions.

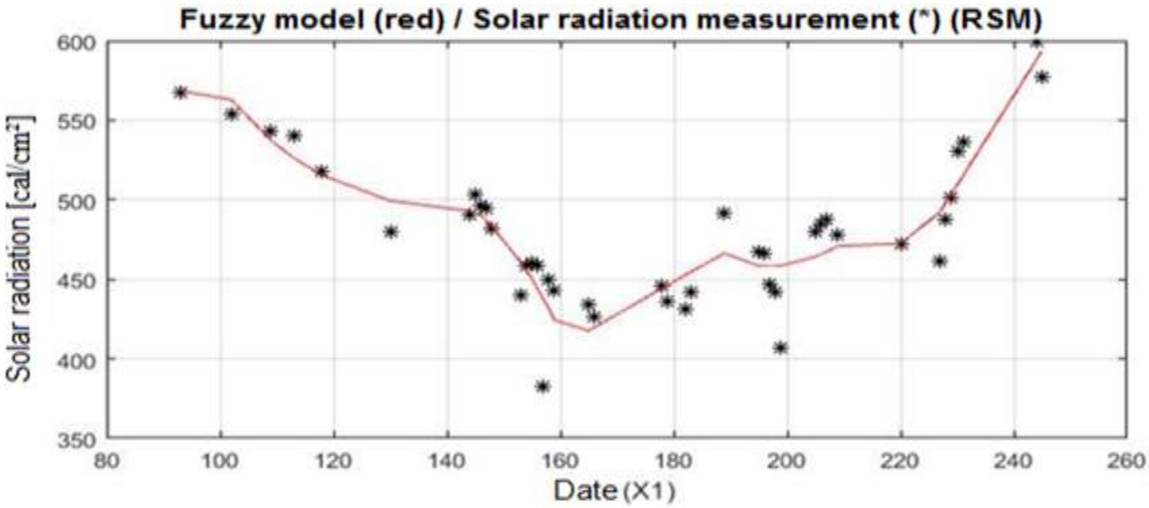

Figure 2 - Fuzzy model results.

VI. CONCLUSION

The fuzzy model of solar radiation incident on surfaces showed good results with respect to approach and complexity. The same presented the approach of the measurement data with a correlation of 0.8894. The fuzzy system also made less complex since it has only one input variable and three polynomial functions, being simpler than the mathematical model of Kondratyev (1977) depending seven input variables and trigonometric functions.

VII. REFERENCES

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