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Global Solar Radiation Modeling using genetic algorithm optimization for estimation of 8-min time step data in Bejaia city (Algeria)

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Abstract

In this paper, the Genetic Algorithm is applied to optimize the parameters of a model with meteorological parameters, (sunshine hours, ambient temperature, air pressure and relative humidity), for estimating 8 minutes global solar irradiation data collected in Bejaia city (Algeria).We compar its performance with four models in the literature (Angstrom-Prescott, Bahel, Newland and Abdalla).

To compare solar radiation estimation equations, the most widely used statistical indicators are the root mean square error (RMSE), Mean Percentage Error (MPE) and the mean bias error (MBE).The proposed model give a relative error of 0,0734% (in absolute value), indicating a very good agreement between measured data and those calculated. This error is acceptable in terms of technique.

Keywords Genetic algoithm, Prediction, Global solar radiation , linear models , bejaia.

1 Introduction

Solar radiation is an important source for many engineer application [1]. Modeling of global solar radiation dates back to the start of the 20th century when [2] developed a relationship between average daily radiation and sunshine duration using the measured data of several locations within US. Angstrom [3] proposed a simple empirical relationship using the measured data from Stockholm. Prescott (1940) later modified the Angstrom relation [4], who used a more generalized Agnot's value from Brunt (1934) [5]. Over the years, researchers have also suggested a nonlinear relationship between sunshine duration and global solar radiation (e.g. Morton [6]; Suehrcke [7]; Yang and all [8]).

The focus of numerous studies is developing methods to estimate solar radiation, in locations where the measured values are not available. The most common estimation method require determining empirical relationships by using correlations between solar radiation and other measured meteorological variables. This method is attractive since it is simple and efficient, and does not involve the acquisition of any additional data [3-4, 9-11]. The meteorological parameters normally used to develop such empirical relationships are: sunshine duration [3,12-14], maximum and minimum air temperature [15,16], relative humidity [12,17], cloudiness [18] and precipitation [15,18]. The introduction into the correlations of meteorological parameters other than sunshine duration, such as air temperature, humidity, and number of rainy days, has led to the second largest model type [19].

Some studies on the characterization of the solar potential in Algeria were realized, for example:

- Modeling daily sunshine duration and global solar radiation in Batna, Oran, Tamanrasset, Bechar and Setif [20-23].
- Monthly average daily horizontal global radiation was used to four locations in Algeria [24].
- The potential solar of Ghardia was applied to four years of data [25].

In this paper, the Genetic Algorithm is applied to optimize the parameters of a model based on meteorological parameters, (sunshine hours, ambient temperature, air pressure and relative humidity), for estimating 8 minutes global solar irradiation data collected in Bejaia city (Algeria).

2 Data use and the meteorological station

The database used in this study is from the Oregon Scientific weather station (Fig.1) for meteorological parameters (ambient temperature, relative humidity, atmospheric and pressure) and the data logger Tarcom measures the illumination. The registrations make themselves every 8 minutes during 2010, 2011, 2012 and 2013. After the deletion of the night data, close to 79000 data are exploitable. Sunshine hours, is the time during which the solar radiation is higher than 120 W/m². To calculate it, we add 8 minutes every time the solar radiation is higher than 120 W/m², while supposing that it keeps this value during all the interval of 8 minutes.We divided this database in two intervals:

The first interval, contains the values of the months February, March, May, June, August, September, November and December for each year. This interval is used to develop some models. The second interval contains the values of the months of January, April, July and October for each year, in order to evaluate the attainment of the models gotten.

The daily extraterrestrial radiation on a horizontal surface was calculated from the following equation[26]:

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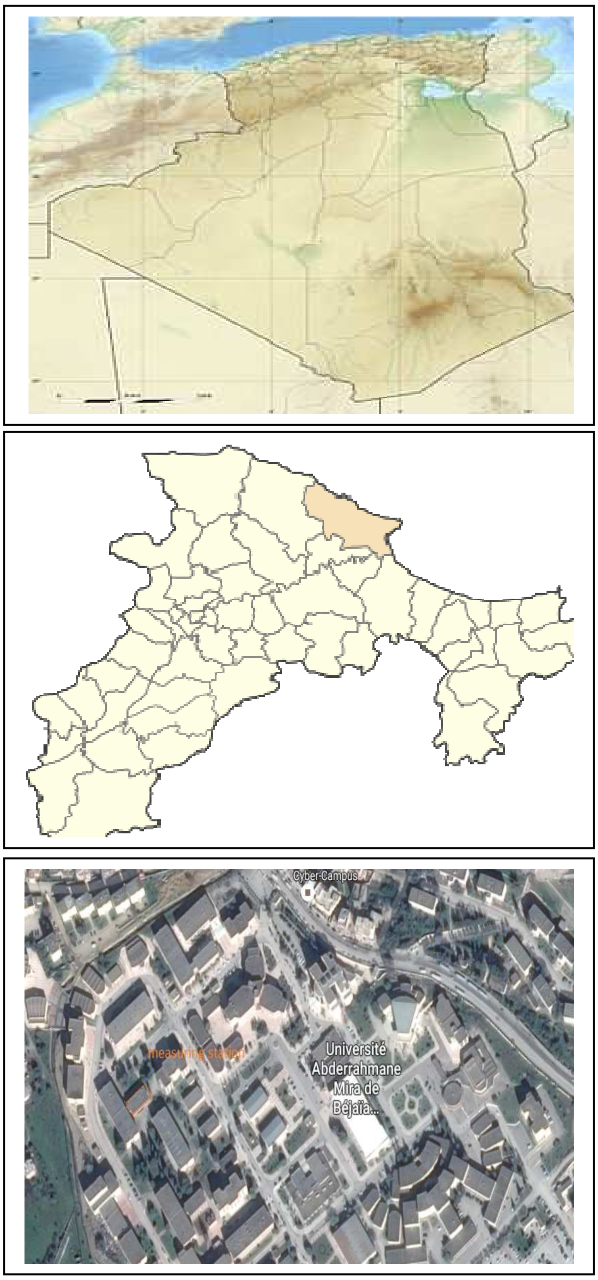
$$I_0 = I_{cs}(1 + 0.0333\cos(360n/365))(\cos\varphi\cos\delta\sin\omega s + \pi\omega s/180\sin\varphi\sin\delta) \quad (1)$$

Where I_{cs} is the solar constant($= 1373\ W/m^2$), $\varphi$is the latitude of the site (36.817.pi/180 rad), δ is the solar declination (rad), ωs is sunrise hour angle, n is the number of the day of year, starting from the first of January.Solar declination and sunrise hour angle can be computed by (2)– (3), respectively [26]:

$$\delta = 23.45\sin[360(284 + n)/365] \quad (2)$$



$$w_s = cos^{-1}(-tan\varphi tan\delta) \quad (3)$$

Fig.1 Position and picture of the meteorological station in Bejaia.

The figure (2) shows that the monthly average global radiation varies $2\ KWh/m^2/day$ for the month December to 6,640 $KWh/m^2/day$during the month of July. Solar energy is available in Bejaia and throughout the year, but with amounts that depend mainly on the season. The average annual global radiation during 2010 is 4,410 $KWh/m^2/day$.

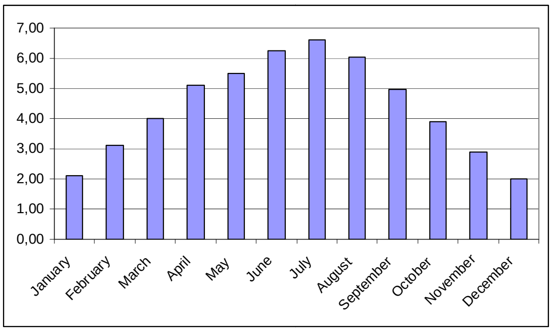


Fig. 2 Irradiation (kWh / m² / d) during 2010 in Bejaia.

Sunshine also varies in the same direction as the global irradiation (Fig. 3). It is higher in the dry season than during other seasons. In summer, the sky is relatively clear, and in other seasons (fall, winter andspring), the sky becomes cloudy. The annual average sunshine during 2010 was 7.84 h (7h 50 min and 4s).

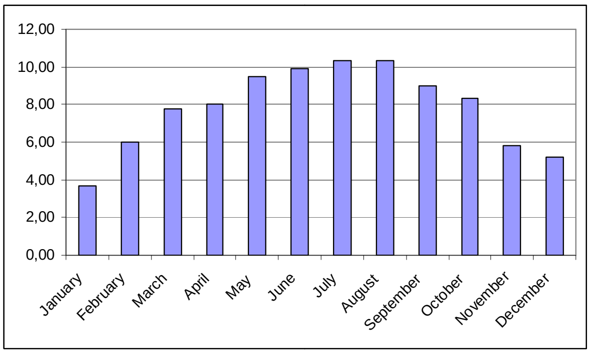


Fig. 3 The sunshine (hours) during 2010 in Bejaia.

The maximum pressure value appears in March, while the minimum is in February. Its annual average during 2010 is 1005.31 hPa. (Fig. 4).

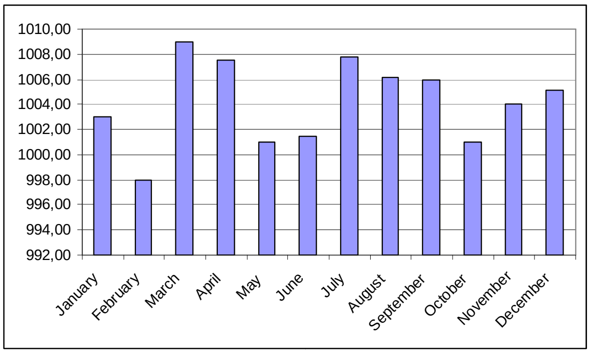


Fig. 4 The atmospheric pressure (hPa) during 2010 in Bejaia.

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In 2010, the temperature varied from 3 to 44 ° C. The maximum monthly temperature averages appear in July (26.79 ° C), while the minimum is in January (13.9 ° C). The annual average temperature in 2010 was 19.52 ° C. (Fig. 5).

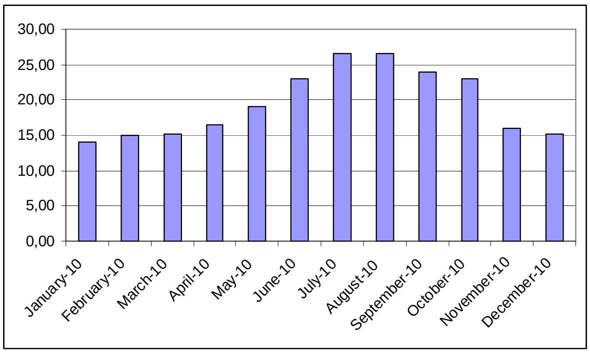

Fig. 5 Monthly averages of ambient temperature (° C) during 2010 in Bejaia

Since the city of Bejaia lies on the Mediterranean, it is very humid. The lowest monthly average above 40%. Its annual average in 2010 was 58.57%. We note that the speed of the evolution of the moisture is the reciprocal of the temperature. This is even more visible with the peaks of the daily variations in the figure (Fig. 6).

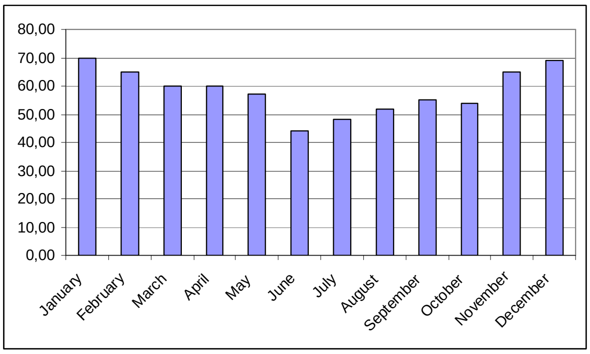

Fig. 6 The relative humidity (%) during 2010 in Bejaia.

3 Genetic Algorithm

Genetic algorithm (GA) has an acceptable characteristic as an optimization tool and present significant advantages more than traditional techniques. It based on the Darwinian principle of natural evolution and species and genetics. They act on a population of individuals that evolves over a series of iterations called generations until a criterion which takes into account a priori the quality of solutions, is checked. Only individuals well adapted to their environment survive and reproduce. They were introduced in 1975 by John Holland and collaborators as search algorithm. Then they were used as optimization tools [27].

These algorithms are part of the class of algorithms called stochastic. Indeed, much of their operation is based on chance. Although using chance, GA are not purely random. They efficiently exploit the information obtained previously to speculate on the position of new points to explore, with the hope of improving the performance [28].

3.1 Parameter

Selection: We used the method of selection of roulette best because it allows individuals to be chosen more often.

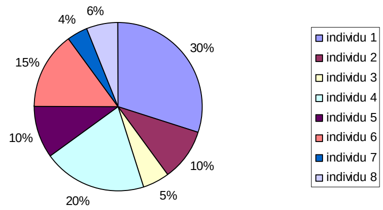

Fig. 7 Proportional roulette

Crossing: We used the method of crossing several site (uniform). This type allows greater diversification of the population.

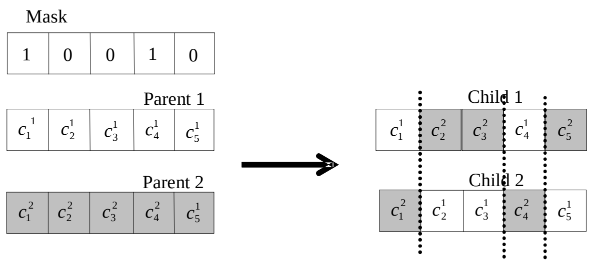

Fig. 8 Uniform crossover

Mutation: According to the mutation probability is chosen, we change the selected genes of chromosome.

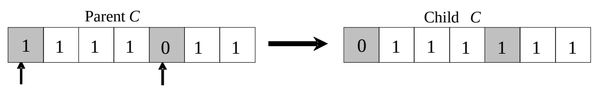

Fig.9 Random mutation.

3.2 Instructions of the GA implemented

A detailed demonstration of the technique adopted in this study is as follows.

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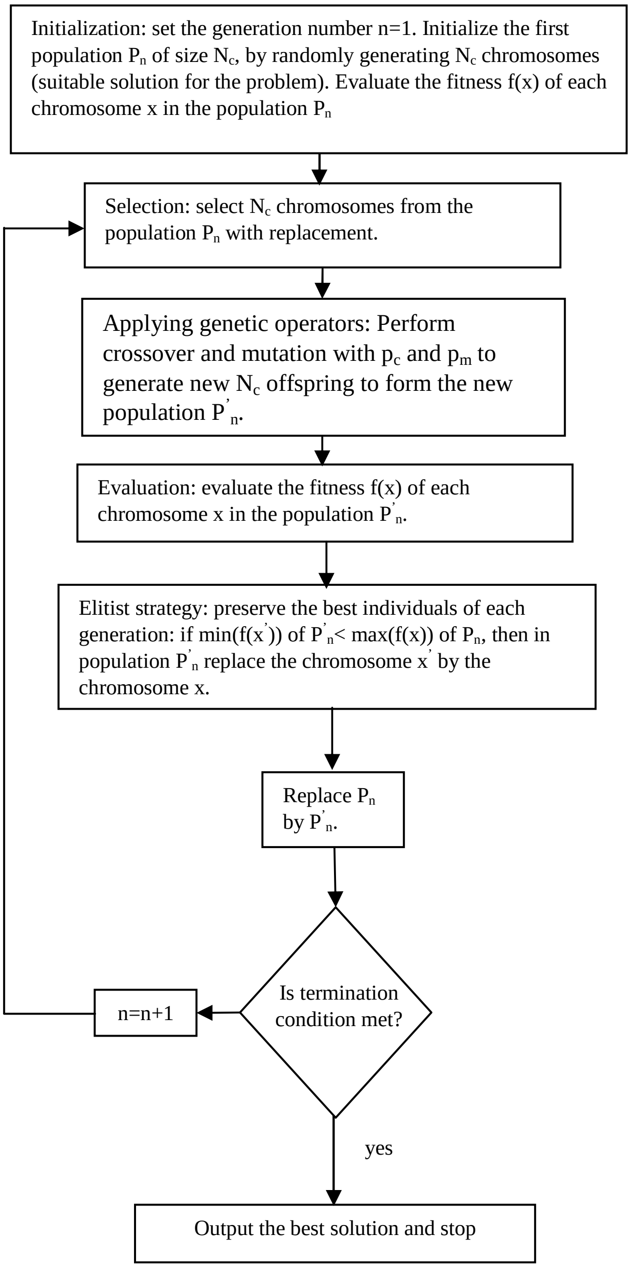

Fig. 10 A scheme of the standard procedure of a basic GA.

4 Proposed method

The objective of this work, was to develop some statistical relations to estimate the global solar radiation H by applying multiple linear regressions to various parameters, such as S/S_0, T, P, and RH, and optimize it using the GA.

We are going to compare his performances to four models of the literature:

Angstrom-Prescott, Bahel, Newland and Abdalla.

Angstrom–Prescott model: [3, 4]

$$H/H_0 = a + b(S/S_0) \quad (4)$$

With: a = 8.01589. 10^{-2} ;b= 0. 7092

Bahel model: [29] Bahel developed a worldwide correlation based on bright sunshine hours and global radiation data of 48 stations around the world, with varied meteorological conditions and a wide distribution of geographic locations:

$$H/H_0 = a + b(S/S_0) + c(S/S_0)^2 + d(S/S_0)^3 \quad (5)$$

With: a = 0.16; b = 0.87; c = - 0.16; d = 0.34.

Newland model [30]: Newland, including a logarithmic term.

$$H/H_0 = a + b(S/S_0) + log(S/S_0) \quad (6)$$

With: a = 0.34; b = −0.4; c = 0.17

Abdalla model [31]: Abdalla modified the Gopinathan model for Bahrain

$$H/H_0 = a + b(S/S_0) + cT + dRH \quad (7)$$

With: a = 0.5289; b = 0.459; c =4.073. 10−3; d = −6.481. 10−3.

To estimate the global solar irradiation in Bejaia, we further constructed the equation containing four variables (S/S_0, T, RH, P), and we found with GA that the correlation coefficient was fairly high.

$$H/H_0 = 14{,}0583 + 0{,}8093\, S/S_0 + 3{,}8061\, 10^{-8}\, T - 0{,}1104\, RH + 0{,}4521\, P \quad (8)$$

To compare solar radiation estimation equations, the most widely used statistical indicators are the root mean square error (RMSE), Mean Percentage Error (MPE) and the mean bias error (MBE).

The RMSE gives information on the short term performance of the correlations by allowing a term by term comparison of the actual deviation between the calculated and measured values. The smaller the value, the better is the model's performance.

However, a few large errors in the sum can produce a significant increase in the RMSE. So low values of RMSE and MPE are desirable.The MBE test provides information on the long term performance. A low MBE is desired. A positive value gives the average amount of over estimation of an individual observation, which will cancel an under-estimation in a separate observation [32, 33, 34, 35].

Root mean square error [36], mean bias errors [29] and mean percentage errors [37], respectively, are:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(H_{i,m} - H_{i,c})^2}{N}} \quad (9)$$

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$$MBE = \left(\frac{\sum_{i=1}^{N} H_{i,m} - H_{i,c}}{N}\right) \quad (10)$$

$$MPE = \frac{\left[\sum_{i=1}^{N}\left(\frac{H_{i,m}-H_{i,c}}{H_{i,m}}\times 100\right)\right]}{N} \quad (11)$$

Where N is the measurements number, $H_{i,c}$ and $H_{i,m}$ are the calculated and measured values of global solar radiation in the day i, respectively.

5 Result and discussion

Regression analysis gives us the ability to summarize a collection of sampled data by fitting it to a model that will accurately describe the data. Each regression model has adjustable parameters, or variables, which can be adjusted in order to achieve close agreement between values of the regression model and the sampled data. In order to evaluate the performance between the proposed model and the regression models, RMSE, MBE, MPE and the correlation coefficient R are used. Table (1) summarizes the comparison results between the regression models and the proposed one.

The correlation coefficients R increase with the number of parameters that is taken in account in the models, while the RMSE values decrease.

Table 1 The RMSE, MBE, MPE and R for the models study.

Model	RMSE (MJ/m²/j)	MBE (MJ/m²/j)	MPE (%)	R
d'Angstrom-Prescott	11,7117	11,2782	55,7809	0,8116
Bahel	2,3021 10^{3}	-1,4976 10^{3}	-5,3589 10^{-3}	0,8556
Newland	25,7395	23,8044	90,6198	-0,5007
Abdalla	15,3113	14,5988	70,7519	0,8942
proposed model Eq (08)	**1,6581**	**0,0036**	**0,0734**	**0,9764**

It can be seen that the model we have developed and delivered to the (8) present the best results compared to other models (Angstrom-Prescott, Bahel, Newland and Abdalla).

The proposed model has a relative error in absolute value of 0,0734%, indicating a very good agreement between measured data and those calculated. This error is acceptable in terms of technique.

The models Angstrom-Prescott and Newland underestimate the global irradiation. The models Abdalla and Bahel overestimate the global radiation.

The values of global radiation estimated using (8)is compared with measured values in figure (Fig. 11).

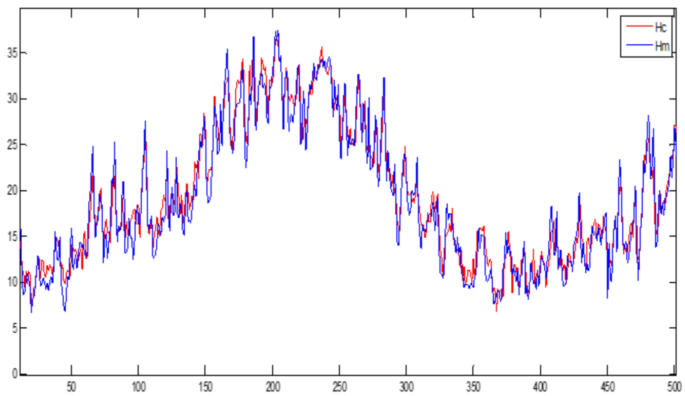

Fig 11. Comparison of measured and estimated values

But the proposed model is in very good agreement with the values actually measured. The maximum deviation was small.

6 Conclusion

In this paper, the Genetic Algorithm is applied to calculate the parameters of regression model based on four meteorological parameters. We compared the developed model with four models in literature (Angstrom-Prescott, Bahel, Newland and Abdalla). It was tested and validated with four years of 8-min solar radiation data collected in Bejaia, Algeria.

We noted that the developed model, driven to better results (R= 0,9764, MBE = 0,0036 MJ/m²/j, RMSE = 1,6581MJ/m²/j and MPE = 0,0734%). This is explained by the fact, that this model considers four meteorological parameters (sunshine hours, ambient temperature, air pressure and relative humidity).

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