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Original Article

Holistic Multiple Regression Models Development for Nigeria Azimuth Angle Determination

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Abstract - *Static solar panel positioning is limited in the value of solar radiation received; solar tracking is required to maximise the radiation collected. In tracking, the Azimuth angle is required for the appropriate positioning of the panel. In establishing the Azimuth, predictive models were developed of multiple regressions through exhaustive literature and experimentation. The Azimuth angle of minutes, hours and months were utilised to develop a multiple regression model, which gives correlation factors above 0.9. This shows a high degree of relationship between the actual and predicted angles. The maximum error was estimated as 3.88%, implying that the predicted models are dependable.*

Keywords - *Azimuth, Correlation, Models, Predicted and Regression*.

1. Introduction

In developing countries like Nigeria, interest in solar energy applications has been growing for electricity. In the studies of solar energy utilisation, data on solar radiation at a given location is a fundamental input, especially for optimal design and the prediction of the solar energy conversion system's performance [1, 2]. The best way of knowing the amount of global solar radiation at a site is to install pyrometers at many locations in the given region and look after their day-to-day maintenance and recording, which is a very costly exercise [3-5].

Despite the importance of solar radiation measurements, in many regions of developing countries, this data is not readily available because of not being able to afford the measuring equipment and techniques involved [6-8]. For regions with no measured data, the common practice is to estimate global solar radiation from other readily measured meteorological parameters. In other words, the alternative approach is to correlate the global solar radiation with the meteorological parameters like sunshine duration at the place where the data is collected [9, 10]. The resultant correlation may then be used for locations of similar Metrological and geographical characteristics for which solar data are unavailable. Attempts have therefore been made to develop empirical relations for estimating insolation from weather data: temperature, humidity, sunshine hour, cloudiness and precipitation, which are easier to measure and are available at many locations [11, 12].

Among all such meteorological parameters, the mean daily sunshine durations are the most commonly used and available parameter [13]. The most popular model is the linear model by angström-Prescott, which establishes a positive correlation between global solar radiation and sunshine duration with knowledge of extraterrestrial solar radiation and maximum daily solar hours [14-16]. The amount of solar radiation that reaches the earth's surface varies from one place to another, owing to the attenuation properties of the atmosphere and the diverse geographical characteristics of the earth's surface. Hence global as well as regional estimates of the distribution of solar radiation have been studied by many researchers [17-20].

However, since solar radiation reaching the earth's surface depends on many factors that are not global, a study of solar radiation under local climatic conditions is essential [21-23].

Nigeria is rapidly increasing its energy consumption and is short on energy supplies as a developing nation. It is, therefore, a matter of interest to assess the significance of solar energy and its utilisation in different fields of application. Furthermore, Nigeria is endowed with an annual average daily sunshine of 6.25 hours, ranging from 5.25 hours in the coastal area to 9.0 hours at the far northern boundary [24, 25]. It has an annual average daily solar radiation of about 5.25kw/m2/day, which varies from 3.5 kW/m^2 day in the coastal area to 7.0 kW/m^2/day at the Northern boundary [26-28].

The data trend (graph) obtained will be the basis of the mathematical model development to model the solar ray collector. The mathematical model is an equation with varying input parameters or formulas derived to simplify complex situations into simple equations through which the variable replacement will lead to the varying output of the azimuth [29-31]. In solar tracking, the light-sensitive device can be used as an input sensor unit to detect and track the sun's position based on sensor readings and generated sun tracking. Data collation will involve states in all geopolitical regions, aiding the formulation of a more dependable model. The model developed will also incorporate parameters essential in specific location orientation to the sunray. The time of the day, latitude and longitude will bring about a robust model that is bound to be more accurate when applied to different states. The range of this work is to develop mathematical modeling for a solar ray collector using the sun's movement from sunrise to sunset (east to west) with the aid of altitude angle and azimuth angle. These angles are calculated through sun-earth relations. Ekiti is the major location for fieldwork; through several experiments and observations, data were generated using theodolite and compass, whose trend will be the basis for the mathematical model development. Other data used were generated from the internet. The main objective of this work is to develop mathematical models for azimuth and altitude angles of various latitudes and longitude within the country. The specific objectives of this work are to collect and collate data by observation of the sun's position at different times and locations, secondly, to utilise collated data to formulate models and validate the developed model with the actual sun's position at the said location. This work would help to generate appropriate azimuth angles for solar tracking, which will increase solar energy reception. The work limitation is a function of the state considered, which is eight for analysis. The number of states considered is less than half of the country's states. The higher the number considered, the higher the accuracy.

2. Seasons of the Year

Table 1. Seasons the occurring at three months intervals[32]

Season	Starts	Months
Spring	21 March	March, April, May.
Summer	21 June	June, July, August.
Autumn/fall	23 Sept	Sept, Oct, November.
Winter	21Dec	Dec, January, February.

In the derivation of the sun-tracking formula, it is necessary to describe the sun's position vector and the collector's normal vector in the same coordinate reference frame, which is the collector-centre frame. Nevertheless, the unit vector of the sun's position is usually described in the earth-center frame due to the sun's daily and yearly rotational movements relative to the earth. Thus, to derive the sun-tracking formula, it would be convenient to use the coordinate transformation method to transform the sun's position vector from the earth-center frame to the earth-surface frame and then to the collector-center frame. By describing the sun's position vector in the collector-center frame, we can resolve it into solar azimuth and solar altitude angles relative to the solar collector, and subsequently, the number of angles needed to move the solar collector can be determined easily.

Reference [33] and [34] developed seven equations to determine the sun's position, where equations (1) - (5), (6) - (7) are to Azimuth and Altitude concerning the hourly, daily conditions on a yearly basis, respectively.

$$\gamma_1 = 180.5 + 65.5\,tanh\left(\frac{6T}{11.5} - 6.65\right) + |22.325 + 24\,cos(0.984D)| \quad (1)$$

$$\gamma_2 = 180.5 + 65.5\,tanh\left(\frac{6T}{11.5} - 6.65\right) - |22.325 + 24\,cos(0.984D)| \quad (2)$$

$$\gamma_3 = 38 - 32\,tanh\,a - |-23 + 24\,cos(-0.984D)| \quad (3)$$

$$\gamma_4 = 348 - 56\,tanh\,a - |-23 + 24\,cos(-0.984D)| \quad (4)$$

$$\gamma_5 = 93 + 24\,cos(0.984D) + 310T - 3720 \quad (5)$$

$$\alpha_1 = 9.667T - 66.669 + 1.8\ell^{(sin\,0.492D + 0.3t - 2.1)} \quad (6)$$

$$\alpha_2 = -10T + 198.2 + 1.8\ell^{(sin\,0.492D - 0.3t + 5.7)} \quad (7)$$

where, $\gamma_1$to$\gamma_5$are for the azimuth angle at various periods of the year, D is the number of days of the year, and T is the time in an hour per day. $\gamma_1$is the azimuth angle for days 1 to 78 and 273 to 366; $7 \leq T < 13$ the azimuth angle on the same days as γ_1; $13 \leq T \leq 18.5$, γ_3 and $\gamma_4$are for azimuth angle on days 79 to 272; $7 \leq T < 12$ and $13 < T \leq 18.5$ respectively, while $\gamma_5$is the azimuth angle for days 79 to 272 at 12hours to 13hours. A is a function of T as in γ_1. α_1, is the altitude angle on either 365 or 366 days for $7 \leq T < 13$and, α_2 is the altitude angle on either 365 or 366 days for$13 < T \leq 18.5$. The developed models were compared with the actual data of the first six months in the year 2015.

3. Materials and Methods

The objective of this project would be accomplished through a thorough and satisfactory literature survey followed by taking into consideration the sun's movement concerning the earth. An intensive literature review was carried out to determine the relationship between Time, Latitude, Longitude, Season and days concerning Azimuth. Fieldworks were carried out using a theodolite, spirit compass, and GPS (global position system) to determine the height of the position considered above the sea level. A Spirit compass was used for the location of the true magnetic North. The Azimuth angles for the Ekiti state were generated with the aid of the theodolite across the horizontal plane, while the altitude angles were generated based on the vertical plane. The data collated were observed based on seasonal conditions. The data for each seasonal period were utilised to develop individual predictive models, and the data considered on a seasonal basis were used to develop multiple regression models. SPSS package [Statistic Package for Social Science] serves as the software for developing the model, and there was also verified with Microsoft Excel. The models developed were validated with the actual position as stipulated by the solar tracking system to ascertain the reliability of the developed models.

3.1. Procedure of Fieldwork Equipment

A theodolite Wild T2, manufactured by Heinrich Company, Germany) was chosen for monitoring the sun's movement for twelve months. A compass will be used to determine where to set up the theodolite tripod, and leveling will be done with the bubble level. Finer adjustments will also be made with the optical plumb bob telescope or the internal electronic tilt meter on the instrument. The theodolite has a turning procedure to verify that they are level to avoid azimuth errors. Once the theodolite is set up and leveled, the reading will be taken consecutively throughout the specified period. These readings were proposed to be taken from the theodolite within thirty minutes intervals starting from the hour of 7 am-6:30 pm daily.

Records collected from the theodolite output will be closely examined and compared to have a précised record of sun movement relative to the area's latitude; a mathematical equation will be generated based on the theodolite records. The equation could be in sinusoidal form depending on the figures obtained from the theodolite. Therefore, the simplification of a complex situation through which a solar ray collector can gain maximum energy from the sun will now be based on the equation derived from the facts obtained during the experiment.

3.2. Method to Determine the Correlation Factor for Azimuth Angle

Table 2. Selected locations and their latitude and longitude

State / City	Latitude (La)	Longitude (Lo)
Yenagua	4.92	6.27
Benin	6.33	5.63
Ikeja	6.58	3.33
Ado-Ekiti	7.63	5.22
Makurdi	7.72	8.62
Abuja	9.08	7.53
Kano	11.1	8.52
Sokoto	13	5.25

$$r = \sqrt{\frac{\sum of Extimated model data}{\sum of Actual data}} \qquad [35]$$

$$r = 0.98$$

Table 3. Parameter used to determine the correlation factor for azimuth

X_A Actual Az (A_{ACT})	X_B Predictive Az(B_{PRED})	X_A - X_B^2
118	105	169
121	119	4
127	134	49
137	148	121
155	162	49
186	202	256
219	212	49
241	222	361
253	232	441
261	242	361
266	252	196
270	257	169
2354	**2287**	**2225**

The correlation factor from the analysis of data obtained and the model developed gives the factor as 0.98. A correlation factor of 1 shows that there is a strong relationship between the two results, and a correlation factor of 0 shows there is a poor relationship between the two results [36, 37]. Therefore correlation factor of 0.98 shows a high degree of the result.

4. Procedures for Testing the Hypothesis of the Azimuth Angle

It is a fact that daily activities are based on decisions taken by the individual, group, cooperate body or state. Those decisions were derived from the results of the generated model.

Table 4. Parameter used to determine the hypothesis testing for azimuth angles

Model Az.X_A	Actual Az.X_B	d	d^2	X_A^2	X_B^2
118	105	1	169	13924	11025
121	119	2	4	14641	14161
127	134	-7	49	16129	17956
137	148	-11	121	18769	21904
155	162	-7	49	24025	26244
186	202	-16	256	34596	40804
219	212	7	49	47961	44944
241	222	19	361	58081	49284
253	232	21	441	64009	53824
261	242	19	361	68121	58564
266	252	14	196	70756	63504
270	257	13	169	72900	66049
2354	**2287**		**2225**	**503912**	**468263**

$$H_o; \mu_A = \mu_B$$

$H_i; \mu_A \neq \mu_B$

$\alpha = 0.05$

$$t = \frac{\overline{X_A} - \overline{X_B}}{S_P\sqrt{\frac{1}{n_A} + \frac{1}{n_B}}} \quad [38]$$

Where,

$$S_P = \sqrt{\frac{(n_A - 1)S_A^2 + (n_B - 1)S_B^2}{n_A + n_B - 2}} \quad [39]$$

Azimuth

$$\overline{X_A} = \frac{\varepsilon x_A}{n} = \frac{2354}{12} = 196.16$$

$$\overline{X_B} = \frac{\varepsilon x_{\mathbf{B}}}{n} = \frac{2287}{12} = 190.58$$

$$S_B^2 = \frac{\varepsilon x^2}{n} - \left(\frac{\varepsilon x}{n}\right)^2$$

$$S_B^2 = 3511.29$$

$$S_A^2 = \frac{\varepsilon x^2}{n} - \left(\frac{\varepsilon x}{n}\right)^2$$

$$S_A^2 = 2700$$

$$S_P = \sqrt{\frac{(n_B - 1)3511 + (n_A - 1)2700}{n_A + n_B - 2}}$$

$S_P = 55.7$

$$t = \frac{\overline{X_A} - \overline{X_B}}{S_P\sqrt{\frac{1}{n_A} + \frac{1}{n_B}}}$$

$$t = \frac{5.58}{21.04} t = 0.26$$

5. Results and Discussions

The sun's movement was taken into consideration regarding the earth by taking the azimuth and altitude angle for 3 months "2 Hours" interval from 7:00 to 18:30. The data obtained was used to develop a mathematical model which is a function of time and day. The correlation factor from the analysis of data obtained and the model developed gives the factor as 0.99, 0.92, 0.98, 0.99, 0.98, and 0.97, respectively, which shows a high degree of the result.

5.1. Developed Multiple Regression Models for Azimuth Angle from January – December 2016

Table 5. Azimuth angles for day 1-78 (7 ≤ t < 13)

Lat(La)	Long (Lo)	Time(T)	Day(D)	Azi (ϒ)
9.08	7.53	7	1	114
6.33	5.63	9	1	112
7.63	5.22	11	31	134
7.63	5.22	12	46	148
7.63	5.22	13	69	159

The multiple regressions are given as follows;

$$\Upsilon = 0.140D + 7.86T + 1.16lo + 5.33la - 1.74 \quad (8)$$

$R^2 = I.0$

Table 6. Azimuth angles for day 273-366 (7≤ T<13)

Lat	Long	Time	Day	Azimuth
7.63	5.22	12.5	273	183
7.63	5.22	11	286	127
9.08	7.53	7	334	114
6.33	5.63	9	334	112
6.58	3.33	12.5	334	174
7.63	5.22	12.5	349	180
7.63	5.22	8	365	118

The multiple regressions are given as follows:

$$\Upsilon = 0.23D + 16.26T + 0.79Lo + 10.81La - 185.23 \quad (9)$$

$R^2 = 0.9$

Table 7. Azimuth angle for day 1-366 (7 ≤ T < 13)

Lat	Long	Time	Day	Azimuth
9.08	7.53	7	1	114
6.33	5.63	9	1	112
7.63	5.22	11	31	134
7.72	8.62	7	334	140
13	5.25	9	334	166
4.92	6.27	11	334	109
7.63	5.22	8.5	349	218
7.63	5.22	10	365	213

The multiple regressions are given below;

$$\Upsilon = 0.38D + 11.66T - 1.12Lo + 8.62La - 47.98 \quad (10)$$

$R^2 = 0.85$

Table 8. Azimuth angles for day 1-75 (13 ≤ T ≤ 18.5)

Lat (La)	Long(Lo)	Time (T)	Day (D)	Azimuth (ϒ)
6.58	3.33	13	1	187
11.1	8.52	15	1	227
7.72	8.62	16	1	238
13	5.25	17	1	246
7.63	5.22	18	46	257
7.63	5.22	18.5	69	267
7.63	5.22	14	31	215

The multiple regressions are given below;

$$\Upsilon = 33.02 + 0.21D + 10.63T + 2.69lo + 1.27La \quad (11)$$

$R^2 = 0.99$

Table 9. Azimuth angles for day 273-365 (13 ≤ T ≤ 18.5)

Lat (La)	Long (Lo)	Time (T)	Day(D)	Azi (Υ)
7.63	5.22	13	273	218
6.58	3.33	13	334	194
11.1	8.52	15	334	231
7.72	8.62	16	334	241
13	5.25	17	334	244
4.92	6.27	18	334	250
7.63	5.22	18.5	349	248
7.63	5.22	14	365	213

The multiple regressions are given below;

$$\Upsilon = 132.84 - 0.18D + 8.57T + 2.98Lo + 0.61La \quad (12)$$

$$R^2 = 0.99$$

Table 10. Azimuth angles for day 1-365 (13 ≤ T ≤ 18.5)

Lat (La)	Long (Lo)	Time (T)	Day(D)	Azi. (Υ)
6.58	3.33	13	1	187
11.1	8.52	15	1	227
7.72	8.62	16	1	238
13	5.25	17	1	246
7.63	5.22	18	46	257
7.63	5.22	18.5	69	267
7.63	5.22	14	31	215
7.63	5.22	13	273	218
6.58	3.33	13	334	194
11.1	8.52	15	334	231
7.72	8.62	16	334	241
13	5.25	17	334	244
4.92	6.27	18	334	250
7.63	5.22	18.5	349	248
7.63	5.22	14	365	213

The multiple regressions are given below;

$$\Upsilon = 57.23 - 0.001D + 9.93T + 2.31Lo + 0.55La$$
$$R^2 = 0.99$$

5.2. Data Collected in Ekiti for the Year 2016 from Jan 1 to March 11, 2016

Fig. 1 represents a graphical view of Azimuth (actual) against Azimuth (predictive) for days 1-78, which stands for Jan 1-March 14, 2016. The day is considered based on 7 days intervals. The graph shows an increment in error as it moves from day 1 to day 15; the error decreases as it moves to day 35, which is Feb 4. In consideration of the day from day 35, the error is at a maximum on day 55. The overall graph maximum error occurs on day 15 between the predicted and actual azimuth, which is $\pm 8^0$. The correlation coefficient is 0.99, which implies a high degree of relationship between the actual and predicted. This implies the predicted is dependable.

Table 11. Azimuth angles for ado-ekiti. day 1 - 78 (13≤T≤18.5)

La	Lo	Time	Day	Azi act.	Azi Pred.
7.63	5.22	16	1	238	238
7.63	5.22	16	8	238	237
7.63	5.22	16	15	239	240
7.63	5.22	16	22	240	242
7.63	5.22	16	29	242	242
7.63	5.22	16	26	244	243
7.63	5.22	16	43	247	246
7.63	5.22	16	50	250	250
7.63	5.22	16	57	253	252
7.63	5.22	16	64	257	256
7.63	5.22	16	71	260	263
7.63	5.22	16	78	264	269
Total				2972	2978

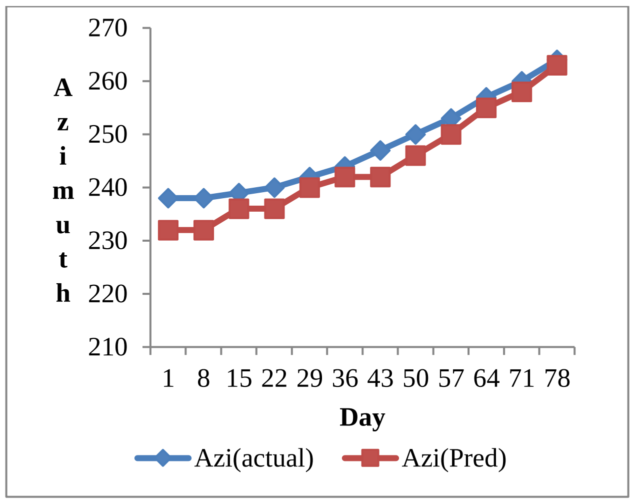

Fig. 1 Azimuth(actual) against azimuth (predictive) for day 1-78 at 16:00

Table 12. Azimuth angles for ado-ekiti. Day 1-75 (7≤T≤13)

La	Lo	Time	Day	Azi (actual)	Azi(Pred)
7.63	5.22	9	1	123	146
7.63	5.22	9	8	121	143
7.63	5.22	9	15	120	141
7.63	5.22	9	22	118	138
7.63	5.22	9	29	116	135
7.63	5.22	9	36	114	133
7.63	5.22	9	43	112	130
7.63	5.22	9	50	109	127
7.63	5.22	9	57	106	125
7.63	5.22	9	64	103	122
7.63	5.22	9	71	100	119
7.63	5.22	9	78	97	117
Total				1339	1576

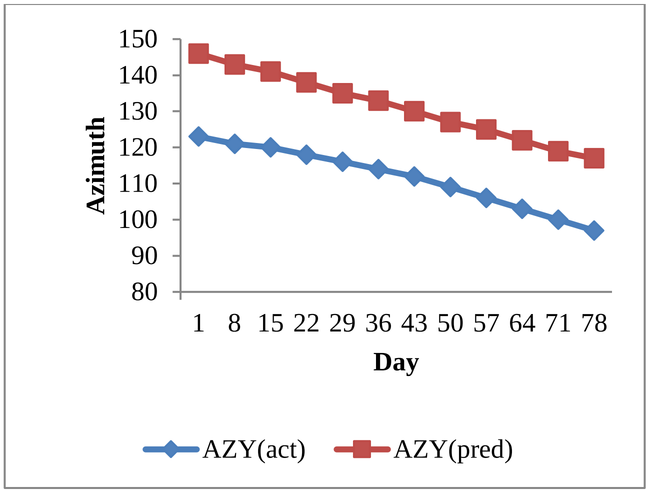

Fig. 2 Azimuth (actual) against azimuth (predictive) for day 1-78 at 9:00

Fig. 2 represents a graphical view of Azimuth (actual) against Azimuth (predictive) for days 1-78, which stands for Jan 1-March 17, 2016. The day is considered based on 7 days intervals. The graph shows the decrease and increase in error between the actual and predicted azimuth is uniform. The overall graph maximum error occurs on day 1 between the predicted and actual azimuth, which is $\pm 26^0$. The correlation coefficient is 0.92, which implies a high degree of relationship between the actual and predicted. This implies the predicted is dependable.

Table 13. Azimuth angles for day 1-75 ($7 \leq T \leq 18.30$)

La	Lo	Time	Day	Azi (actual)	Azi (Pred)
7.63	5.22	8	1	118	105
7.63	5.22	9	8	121	119
7.63	5.22	10	15	127	134
7.63	5.22	11	22	137	148
7.63	5.22	12	29	155	162
7.63	5.22	13	36	186	202
7.63	5.22	14	43	219	212
7.63	5.22	15	50	241	222
7.63	5.22	16	57	253	232
7.63	5.22	17	64	261	242
7.63	5.22	18	71	266	252
7.63	5.22	18.5	78	270	257
Total				2354	2287

Fig. 3 represent a graphical view of Azimuth (actual) against Azimuth (predictive) for days 1-78, which stands for Jan 1-March 17, 2016. The day is considered based on 7 days intervals. The graph shows an increment in error as it moves from day 15 to day 30; the error decreases as it moves to day 40, which is Feb 9. In consideration of the day from day 40, the error is at a maximum on day 50. The overall graph maximum error occurs at 11:00 am between the predicted and actual azimuth, which is $\pm 13^0$. The correlation coefficient is 0.98, which implies a high degree of relationship between the actual and predicted. This implies the predicted is dependable.

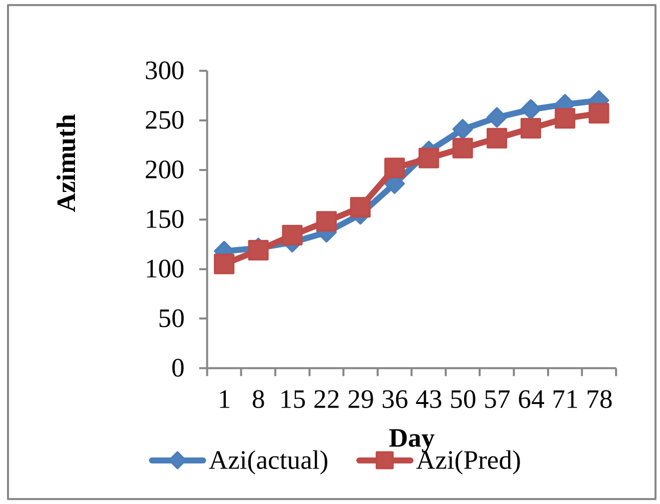

Fig. 3 Azimuth (actual) against azimuth (predictive) for day 1-78 at 7:00 -18:30

Table 14. Azimuth angle for day 1 ($7 \leq T \leq 18.30$)

La	Lo	Time	Day	Azi (act)	Azi Prd.
7.63	5.22	7	1	115	94
7.63	5.22	9	1	123	117
7.63	5.22	11	1	143	140
7.63	5.22	13	1	189	202
7.63	5.22	15	1	228	222
7.63	5.22	17	1	244	242
		18.30	1	248	257
Total				1290	1274

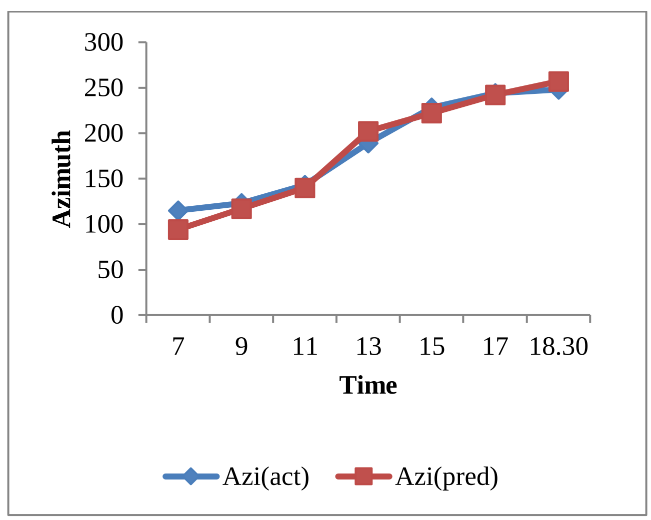

Fig. 4 Azimuth (actual) against azimuth (predictive) for day 1 at 7:00 - 18:30

Fig. 4 represents a graphical view of Azimuth (actual) against Azimuth (predictive) for day 1, which stands for Jan 1, 2016. The time is considered based on 2 hours interval. The graph shows an increment in error as it moves from 7:00 am to 9:00 am; the error decreases as it moves to 13:00, which is 1:00 pm. In consideration of the time from 1:00 pm, the error is at the maximum of 3:00 pm. The overall graph maximum error occurs at 7:00 am between the predicted and actual azimuth, which is ±210. The correlation coefficient is 0.99, which implies a high degree of relationship between the actual and predicted. This implies the predicted is dependable.

Table 15. Azimuth angles for day 45 (7≤T≤18.30)

La	Lo	Time	Day	Azi (act)	Azi (pred)
7.63	5.22	7	45	107	110
7.63	5.22	9	45	111	134
7.63	5.22	11	45	128	157
7.63	5.22	13	45	186	202
7.63	5.22	15	45	238	222
7.63	5.22	17	45	253	242
7.63	5.22	18.30	45	258	257
Total				1281	1324

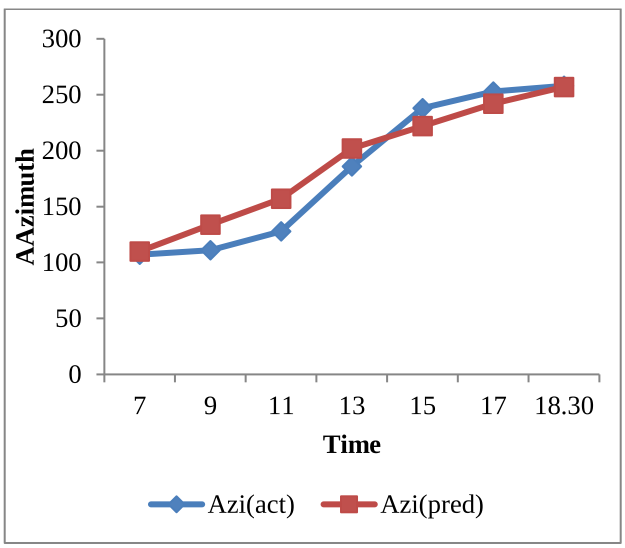

Fig. 5 Azimuth (actual) against azimuth (predictive) for day 45 at 7:00 - 18:30

Fig. 5 represents a graphical view of Azimuth (actual) against Azimuth (predictive) for day 45, which stands for Feb 14, 2016. The time is considered based on 2 hours interval. The graph shows an increment in error as it moves from 7 am to 11 am; the error decreases as it moves to 14:00, which is 2 pm. In consideration of the time from 2:00 pm, the error is at a maximum of 5:00 pm. The overall graph maximum error occurs at 11:00 am between the predicted and actual azimuth, which is ±30. The correlation coefficient is 0.98, which implies a high degree of relationship between the actual and predicted. This implies the predicted is dependable.

Table 16. Azimuth angle for day 75 (7≤T≤18.30)

La	Lo	Time	Day	Azi (act)	Azi (pred)
7.63	5.22	7	75	94	122
7.63	5.22	9	75	99	145
7.63	5.22	11	75	110	168
7.63	5.22	13	75	199	202
7.63	5.22	15	75	257	222
7.63	5.22	17	75	266	242
7.63	5.22	18.30	75	269	257
Total				1294	1358

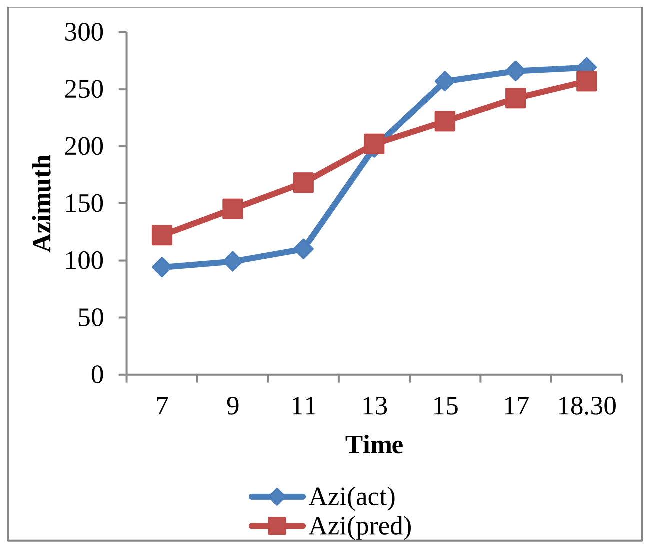

Fig. 6 Azimuth (actual) against azimuth (predictive) for day 75

The time is considered based on 2 hours interval. Fig. 6 graph shows an increment in error as it moves from 7 am to 11 am; the error decreases as it moves to 13:00, which is 1 pm. In consideration of the time from 1:00 pm, the error is at a maximum of 3:00 pm. The correlation coefficient is 0.97, which implies a high degree of relationship between the actual and predicted. This implies the predicted is dependable.

5.3. Maximum Error Developed by the Model

Error is a deviation from accuracy. In statistics, an error is not a mistake but rather a difference between computed, estimated, or measured values and the accepted true, specified, or theoretically correct value. Terms of systematic and random errors or the proximity of measurement results to the true value [40]. Error in percentage can be estimated as given in the equation below:

$$Max..error..\% = \frac{Actual - Measure..value}{Max...Possible..value} \times \frac{100}{1}$$

The maximum error for the azimuth will always occur on February 24 at 2:00, which is 49, and the actual value for the azimuth at this time is 55

Therefore the Maximum error % for azimuth can now be evaluated

Actual value = 21

Measured value = 7

Maximum value = 21

$$Max..error..\% = \frac{21-7}{360} \times \frac{100}{1}$$

$$Max..error..\% = \frac{14}{360} \times \frac{100}{1}$$

$$Max..error..\% = 0.038 \times 100 = 3.8\%$$

5.4. Validation

The purpose of validation is to ensure the integrity of all techniques and procedures for the development of a solar tracking model to establish confidence in the model generated to run a solar tracker.

The following steps were strictly followed in the cause of validating the generated model:

1. Selecting a working solar tracking system
2. Obtaining data for azimuth and altitude angles through the tracking system for 5 days.
3. Acquiring data for azimuth and altitude angles from the developed model evaluation of the difference between the results.

6. Conclusion and Recommendations

6.1. Conclusion

This work has been used to successfully develop a mathematical model for accurately positioning the solar tracker on the earth rightly with the sun's position using the data of sun movement generated with the aid of a compass and theodolites from the experimental procedure. The resulting model possesses a high correlation factor showing a high level of accuracy. The implementation of the model will enhance the utilisation of photovoltaic panel solar trackers, and the amount of energy (electricity) generated per kWh/day will be increased. The multiple correlation coefficients are given as; 0.92, 0.98, 0.99, 0.98 and 0.97, respectively and the maximum error is given as; 3.88%, which implies a high degree of relationship between the actual and predicted. This implies the predicted is dependable.

6.2. Recommendations

Considering the nature of the model in this work, the following recommendations are hereby suggested:

- During the generation of data, a data logger should be applied to ensure more accurate data are collected in developing a highly effective model.
- Models developed can be utilised in tracking sun radiation at optimum levels for drying grains or for charging batteries using photovoltaic cells.

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