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NUMERICAL ANALYSIS AND SIMULATION OF ELECTRICAL DISCHARGE PATH UNDER NORMAL AND SPECIFIC CONDITIONS

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ABSTRACT

In this study, the pattern of lightning which is a type of an electrical discharge is modelled. While modeling is being established, electrical potential distribution calculation, probability correlations, random number generation algorithms and matrix calculations are used. The potential distribution calculation is fulfilled by using the Finite Difference Method. Developing the random number generation algorithm for representing the charges distributed randomly in the air, the result is obtained by adding the probability calculation. Model is simulated on Matlab program under the general and specific conditions. The study provides the same results obtained by the actual studies and methods used for the modeling of lightning as well as it has some additional properties such as "multi-directional expansion". Also the model represents positive results in visual meanings when it's compared the natural behavior of the lightning.

Keywords: Lightning; Discharge path; Numerical simulation

1. INTRODUCTION

Considering the lightning occurs in a very large area in the atmosphere in very high current and voltage values; it's hard to imitate the lightning in a laboratory. Also, each lightning path ends with a different form from the other because of the changing conditions around where it happens. Because of we can't figure out the load distribution and the pressure of air, or the temperature or the other variables at the time that a lightning occurs, it's so hard to establish a model of lightning path [1-3].

There are a few methods in order to create images look like a lightning such as Percolation Theory [4-7], Laplacian Growth, Dielectric Breakdown Model (DBM) [8-10] or Random Middle Point Displacement Algorithm [11, 12].

Each of these methods constructs a lightning path image without using any electrical terms or calculations but only probability and mathematical transactions except the DBM Model. DBM takes the potential values around the lightning into account and calculates it for each step of the lightning but the next step of the lightning at any time in each step is chosen randomly.

These methods of modeling the lightning creates similar results to the real lightning and also works very fast in simulations but the aspect of not including any electrical algorithms in it and not being on a physical base makes these methods artificial or empirical.

2. SUGGESTED MODELS

There are two models suggested in this paper: Four-ways and eight-ways growing models. Both models have the same comprehension in the programming diagram. The differences come out in the programming codes and the number of actualized inquiries during the simulation steps.

The eight-way growth model has never been developed before. All the modeling so far has been designed to consider the lightning moves forward and grows in four main ways: left, right, top and bottom. The eight way growing model allows the lightning to go additional diagonal ways such as bottom left.

3. PROGRESS STEPS OF THE MODELS

There are several steps achieved during the simulation that are both the same for each model:

First Step: The lightning configuration offered by Niemeyer based on the DBM Configuration is set for establishing the form of earth and start point of the lightning.

Second Step: The potential values around the lightning starting point are calculated by using the Central Finite Differences Method and iterations. Solving the boundary conditions is carried out by applying the Neumann Boundary Conditions.

Third Step: By looking at the last position of the lightning shape, the neighbour points have to be determined for the next step of the lightning that constitutes the most critical step for the model.

	•	0	•			
	•	0	•			
	•	0	0	•		
		•	0	0	•	
			•	0	•	
				•		

Fig. 1: The neighbour points at a time “t”.

It’s very important and hard to take the neighbour points into account only one time in the probability evaluation to get the true results especially in the eight-way growing model. The probability of a neighbour point among all neighbour points can be given as [8]:

$$p(i, j) = \frac{(V_{i,j})^{\eta}}{\sum (V_{i,j})^{\eta}} \tag{1}$$

Once the probability values calculated for each neighbour point based on its potential value and the other neighbour values; the first part of the probability is ended.

The η power in the equation (1) provides to balance the difference of probability values among the neighbour points. For the higher values of η, it gets harder for the upper points to be selected as the next step but for the values around 1, it makes nearly every point selectable but values higher then 1.5, it gets nearly impossible for the upper points to be selected even they get very high values in the random number generation step that is explained in the bottom.

Giving the opportunity to any neighbour point to be selected as the next step of the lightning, there must be an algorithm that would disorder the probability values calculated because these values depends on the potential differences of the points and they always increase from the lightning to the earth. So, making the upper points is able to select as the next step, the "random point generation" algorithm gets involved at this point.

For every neighbour point, a random number between 0-1 is regenerated and multiplied by its probability value that was calculated according to the potential. We can assume this "random numbers" attached to these neighbour points as they are "loads" distributed randomly in the air in rainy conditions.

0.08	0	0.02		
0.09	0	0.01		
0.12	0	0	0.03	
	0.09	0	0	0.09
		0.11	0	0.14
			0.22	

(a)

0.67	0	0.42		
0.49	0	0.71		
0.82	0	0	0.35	
	0.29	0	0	0.89
		0.11	0	0.11
			0.15	

(b)

0.05	0	0.01		
0.04	0	0.01		
0.10	0	0	0.01	
	0.03	0	0	0.08
		0.01	0	0.02
			0.03	

(c)

Fig. 2: The probability values generated random numbers and multiplied final values, respectively.

After the final probability values is calculated, the neighbour point that has the highest value gets selected as the next step of the lightning, the point which has 0,10 points shown in gray color in Fig. 2 (c).

This loop continues from the first step until the last one until the lightning reaches the bound, the earth.

Using the η factor effectively and taking the "random number generation" algorithm into account, the nature of the lightning is achieved in the model successfully because we want the lower points to be selected more often against the upper points and the lightning to go in the down direction generally.

There are some results of the model in a 64 × 64 matrix, for 0 V lightning and 100 kV earth potential difference values and η = 1.3 which is iterated for 100 times for the potential calculation in each step of growing are listed below. The reason for giving 0 V value to the lightning and 100 kV to the earth is to ensure to put the probability values in increasing order from top to bottom side, so it looks more logical. If the values are appointed as 100 kV to the lightning and 0 V to the earth as it’s in reality, the probability values would be decreasing for down direction. It doesn’t matter the values of the boundaries; there is a potential difference between them.

Fig. 3: The results for 64 × 64 matrix using four-ways growing model

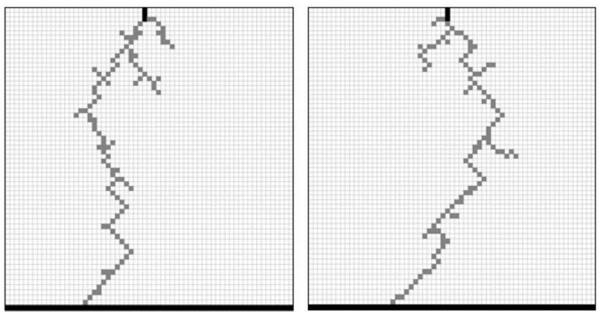
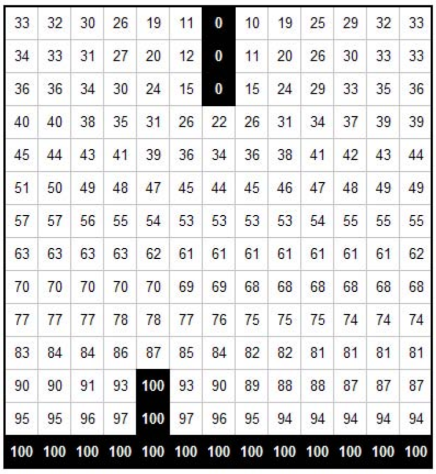


Fig. 4: The results for 64 × 64 matrix using eight-ways growing model

Considering the results of the simulation, we can say that there is a visual difference between the two models seven in the 64 × 64 resolution. This difference gets clearer for the lower resolutions but for higher values as 256 × 256, it would be nearly the same because of the nature of human eye so that two steps like bottom and right in the four-ways model would be established in one step in the eight-ways model but it wouldn’t be noticed.

4. SPECIFIC CONDITIONS

The both models are improved by adding the "apartment application" that can be expressed as a specific condition of the general model. Putting a protrusion in different locations and heights just on the bottom boundary which represents earth in the study and giving the boundary value (100 kV in this example), the configuration of the apartment model is achieved. The protrusion affects the linear distribution of the potential and gets higher values around itself because it has the highest value (100 kV) that causes the lightning come to its direction depending on the height and the location of the protrusion. In Fig. 5; it's clear that the potential values are higher around the protrusion that represents a two-floor apartment on the earth carrying the same boundary values with it; 100 kV. The upper boundary values, 0 V represents the starting point of the lightning that would grow in upcoming steps.



33	32	30	26	19	11	0	10	19	25	29	32	33
34	33	31	27	20	12	0	11	20	26	30	33	33
36	36	34	30	24	15	0	15	24	29	33	35	36
40	40	38	35	31	26	22	26	31	34	37	39	39
45	44	43	41	39	36	34	36	38	41	42	43	44
51	50	49	48	47	45	44	45	46	47	48	49	49
57	57	56	55	54	53	53	53	53	54	55	55	55
63	63	63	63	62	61	61	61	61	61	61	61	62
70	70	70	70	70	69	69	68	68	68	68	68	68
77	77	77	78	78	77	76	75	75	75	74	74	74
83	84	84	86	87	85	84	82	82	81	81	81	81
90	90	91	93	100	93	90	89	88	88	87	87	87
95	95	96	97	100	97	96	95	94	94	94	94	94
100	100	100	100	100	100	100	100	100	100	100	100	100

Fig. 5: The affect of the protrusion to the potential distribution in the apartment model.

The probability of the lightning to be affected and get near to the apartment increases when the height of the protrusion increases or it gets nearer to the lightning in vertically because the potential distribution gets higher values in this area and the probability calculations are based on the potential values generally.

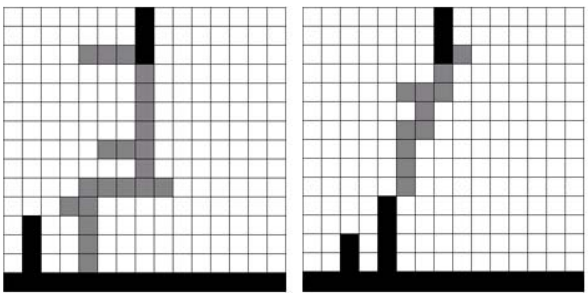


Fig. 6: The results for 15 × 15 matrix using four-ways growing model for one and two apartments respectively in different floor heights.

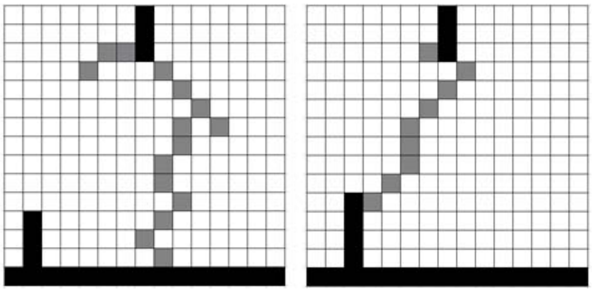


Fig. 7: The results for 15 × 15 matrix using eight-ways growing model for one and two apartments respectively in different floor heights

Running the simulation for the apartment model in the same and different conditions (same height different locations or different heights for the same locations), the results are shown in the table below:

Table 1: The result for 15 × 15 matrix using eight-ways growing model under different apartment conditions.

# of Floors	Location	Hit (%)	Pulling (%)	# of Steps
1	0.5	20	5.68	13
1	0.428	0		
1	0.357	0		
1	0.285	20		
1	0.214	40		
2	0.5	20	8.96	11
2	0.428	0		
2	0.357	40		
2	0.285	40		
2	0.214	80		
3	0.5	20	14.24	11
3	0.428	40		
3	0.357	20		
3	0.285	60		
3	0.214	100		
4	0.5	20	16.54	11
4	0.428	20		
4	0.357	60		
4	0.285	100		
4	0.214	100		
2 - 4	0.357 & 0.214	60	15.7	10

In Table 1, the location values represent the rate of the distance between the apartment on earth and the starting point of the lightning horizontally to the lightning's height vertically. The lower values means that the location of the apartment is closer the starting point of the lightning because of the height of the lightning are always the same in 15 × 15 matrix. The hit percentage shows the probability of the apartment to be hit by the lightning strike according to its position. The Pulling percentage represents the rate of distance between the lightning strike point and the starting point vertically to the height of the lightning which is constant (15) in the example. The number of steps shows the number of steps of the lightning to strike.

Looking into the values in the Table 1 generally we can reach the results below generally:

- For the same floor heights, comparing the location and the hit percentage; generally, the percentage of hit increases when the location value decreases that means the apartment comes closer to the lightning vertically. This result is as it's expected as in the nature.
- Comparing the floor heights and the hit percentage, we can say that; the probability of the apartment to get stroked increases when its height increases. Also this result is as it's expected; the sharper the protrusion is the more chance to be hit.
- Comparing the floor heights and pulling percentage, again, the percentage increases for the higher values of the height. Also this result is as it's expected because when the floor increases, the potential distribution around the apartment gets higher values that affect the probability values of the points that would be selected in growth process.
- Comparing the floor heights and the average step number, the step number decreases when the floor height increases because it takes fewer steps to reach a higher apartment; as expected.

Looking generally to the comments above, we can say that the model gives realistic results parallel to the nature of the lightning.

5. CONCLUSION

When we compare the four-way growing model and the eight-way growing model:

- The flow diagram of the simulation, the number and type of the steps actualized are the same and the simulation runs in the same logic and calculations.
- The number of inquiries executed by eight-way growing model is about three times more than the four-way model and each inquiry is more complicated because of the increasing number of the neighbour points, means that longer simulation time for the same matrix values.
- The calculation of the probability values can not be executed in the same way in both models because of the increased number of inquiries executed so it takes more time in the simulation to get the final probability values in each step of the growing means longer simulation time.
- Because of the nature of the potential distribution around a protrusion gets higher values in the bottom left or right points than the bottom point, the lightning grows much more in the diagonal direction than the perpendicular directions, we can say that lightning is more oblique to go in the diagonal directions so the eight-way model is more realistic than the four-way.

Comparing the suggested models with the existing models such as; Percolation Theory, Random Midpoint Displacement Algorithm or Laplacian Growth;

- The suggested models take more time in the simulation for the same matrix sizes because of the number of iterations.
- The suggested models' every step is based on a physical or electrical collation. The calculation of the potential distribution with the finite difference method or the random point generation algorithm representing the ions and the loads distributed randomly in the air separates the model from the existing ones that use only mathematically probability functions. Only the Laplacian growth model uses the potential distribution calculation but chooses the neighbour point randomly.
- First time, it's allowed to grow in the diagonal directions additionally the perpendicular directions among the all models and realized that lightning is more desirous to go forward in diagonal directions because of the nature of the potential distribution.
- The apartment configuration lets us understanding the nature of the lightning in better terms and gives the opportunity to develop the lightning protection systems.
- The models are open to add additional algorithms like the temperature or the pressure in air if they are defined as new algorithms someway like the random number generation is used to represent the ions in the air. So the model would represent the lightning more realistic.

Nowadays, we reach much more data about the storms, lightning and air conditions with the developing technology in the satellites or other equipments in the meteorology that lets us to understand the nature of the lightning and other air cases. That would increase our knowledge about the storms and lightning much more rapidly.

Understanding the lightning behaviour in much more realistic ways; it could save human lives and other livings. Also the protection and the provision of continuous production are very important terms in the industry section where the interruption in the production costs millions of dollars in these days.

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