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Solar Insolation Simulation by Cellular Automata and Applications to Smart Home

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Abstract: Solar insolation influences important factors such as the indoor sunshine and room temperature. For a smart house, the amount of power generation of a photovoltaic generation depend on the solar insolation. However, knowledge required to evaluate the influences may not be readily available. We aim to build a solar insolation simulator that can be used without professional knowledge and detailed information. The simulator has simplicity and flexibility of a computational model of cellular automata. The advantage of this simulator is in an easy setup. Since this simulator needs only a floor plan diagram, its detailed knowledge is unnecessary. Moreover, the merit of the application by having created by the cellular automaton is also an advantage of this simulator.

Keywords: cellular automata, living climate, insolation

1 INTRODUCTION

Solar insolation influences important factors in designing a smart home such as the indoor sunshine, room temperature and the amount of power generated by a photovoltaic generation for the house installed. Many simulators of solar insolation have been already developed [1][2].

However, professional knowledge such as architectonics is required for those simulators, and it would be difficult to use those simulators for novices. For example, when Daysim [1] performs a simulation, it requires the three-dimensional model by CAD (Computer Aided Design). Therefore, a simulation cannot be performed without the knowledge of CAD. Further, information required to use those simulators described above (such as the quality of the material of a wall, the form of a roof, and information on the surrounding residence) may not readily be available.

We aim to develop a simulator which requires a floor plan diagram but neither professional knowledge nor detailed information. By performing a simulation only from a floor plan diagram, the time and effort for model creation is reduced.

Section 2 explains a definition of cellular automaton modified to simulate a light ray.

Section 3 presents the outline of the simulator.

Section 4 deals with the application of the simulator. The function and simulation result are also presented.

2 CELLULAR AUTOMATON MODEL

2.1 Cellular Automata

Cellular automata are a computational model composed of homogeneous cells each of which has the same number of states and the same set of rules to change the state. These cells are arranged in a regular lattice such as a square lattice and a hexagonal lattice. We use a two dimensional square lattice. In discrete time progresses, each cell determines the own state by an interaction from the state of itself and its neighborhood [3].

The cellular automaton can express a complicated phenomenon easily only by applying the same transition rule as all the cells. Moreover, it also has the pliability which can express another new phenomenon by adding a transition rule. For simplicity we used cellular automata to build solar insolation simulator.

2.2 Cellular Automata for the Simulation of Solar Insolation

The outline of cellular automata for the simulation of solar insolation is shown below.

The state s of a cell is a collection of states (as in the formula (1)): c is a type of a cell; a is the degree of incidence angle; x and y are the movements to the direction of x and y from an incidence position, respectively; and d is a direction of movement.

$$s = (c, a, x, y, d) \tag{1}$$

The type of a cell c is air, a wall, or light. Furthermore, when c is light, a cell has the information on the degree of incidence angle *a*, the amount of movements *x* and *y*, and a direction of movement *d*.

The degree of incidence angle *a* is the degree of incidence angle of sunlight. The position of the sun changes with time. Therefore, it is necessary to change the degree of incidence angle according to the date and time.

The amount of movements *x* and *y* are value used when determining a direction of movement, and *x* and *y* takes both of positive.

A direction of movement *d* is a direction where light actually progresses, and there are eight directions as shown in Fig.1. There is the degree of incidence angle to a range of 0 to 360 degrees, but the light cannot move to the direction of this angle correctly on grid-like space. Therefore, by choosing a direction of movement appropriately, light moves the degree of incidence angle approximately.

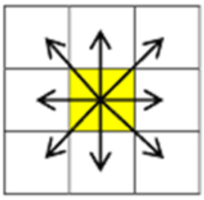

Fig. 1. The direction of movement of light

Each cell determines the next state by applying the transition rule *f* to determine the next state $s_{i,j}^{t+1}$ based on the state of the own cell and neighbor cell as in the following update rule (2). The symbol $s_{i,j}^{t}$ indicates the state of the cell in the coordinate (*i*, *j*) at the time *t*.

$$s_{i,j}^{t+1} = f(s_{i-1,j-1}^{t}, s_{i-1,j}^{t}, \cdots, s_{i,j}^{t}, \cdots, s_{i+1,j+1}^{t}) \qquad (2)$$

3 THE OUTLINE OF THE SIMULATOR

3.1 The Outline of the Simulator

A floor plan diagram is used for a simulation, and 1 pixel is set up as one cell. The state of each cell is distinguished by the color of a pixel when a floor plan diagram is read.

There are three kinds of sunlight: direct sunlight, skylight and catoptric light from the ground. But, for simplification of a setup, only direct sunlight with the largest amount of solar insolation is considered in this simulator.

The simulation is performed in two dimensions. And a floor plan top is set up north.

3.2 The Procedure of the Simulation

Operation of the simulator consists of arrangement of light, movements of light, and those repetitions. The details of three operations are shown below.

3.2.1 Arrangement of Light

If the type of a cell is air and the cell is on the edge of the screen, the type of the cell is made to change light. For example, sunlight is incident from the right and under of the screen at 9:00 (refer to Fig. 2). Moreover, light sets up the degree of incidence angle which suits at time (refer to Fig. 3).

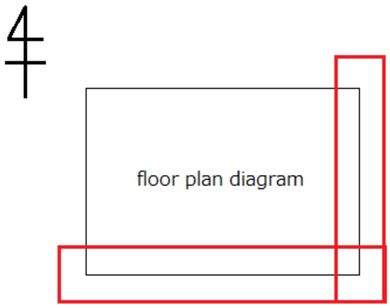

Fig. 2. The incidence position of light at 9:00

Fig. 3. The degree of incidence angle

3.2.2 Movements of Light

If there is the light whose the direction of movement turned to the own cell at neighborhood and the type of own cell is air, the type of the own cell changes to light. Moreover, if a type of a cell is light, the cell changes to air. And other cells do not change. This transition rule expresses movement of light.

Further, when changing in light, the degree of incidence angle *a* succeeds the same angle and the amount of movements increases according to a direction of movement.

A direction of movement is determined by the following formula (3).

$$d^{t+1} = \begin{cases} d_p : if\ |a - \theta_p| < |a - \theta_q|\ then \\ d_q : if\ |a - \theta_p| > |a - \theta_q|\ then \end{cases} \qquad (3)$$

The direction of movement of light is chosen from two directions of movement assumed, d_p and d_q (If it is 180 degrees to 135 degrees, they are the left or the upper left: refer to Fig.4). Angles θ_p and θ_q are calculated and the angle θ near the degree of incidence angle is chosen as a direction of movement. θ is determined by the formula (4).

$$\theta = sin^{-1}\frac{y}{\sqrt{x^2+y^2}} \quad (4)$$

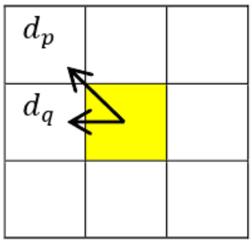

Fig. 4. The example of a direction of movement

3.2.2 Repetitions

If the cell which exists in the move direction of light is a wall or the edge of the screen, another cell is made to change to light and light is moved.

When changing and moving a cell of all the incidence positions to light, the degree of incidence angle is reduced by 1 degree and the simulation is repeated till finish time.

4 APPLICATION OF THE SIMULATOR

4.1 Simulation of Daylight of a Residence

Fig. 5 shows a simulation result of the snapshot daylight at 9:00 a.m. A dark portion expresses a wall and a bright portion expresses a sunshine portion. If a cell has changed to light at the time, the simulator expresses the cell as a sunshine portion.

Moreover, Fig. 6 shows daylight through the daytime. A cell with long time of type of light is expressed more brightly.

These two simulation result (Fig. 5 and Fig. 6) demonstrate that the simulator can be used to evaluate the indoor condition of daylight both at a specific time and during a daytime.

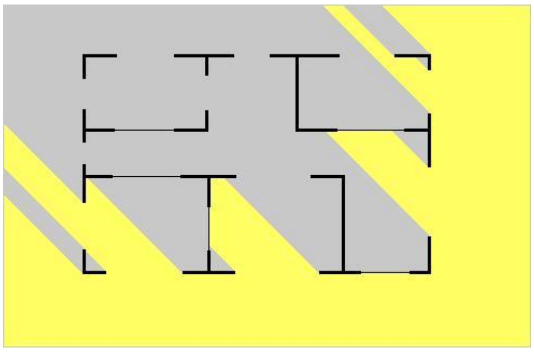

Fig. 5. Daylight of a residence at 9:00

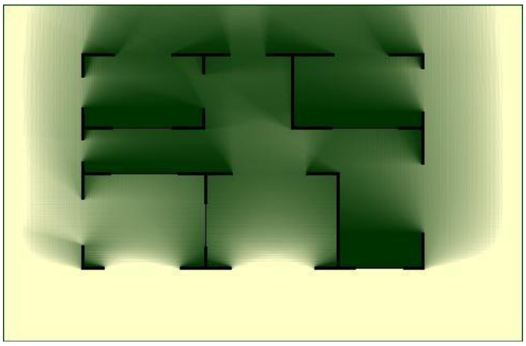

Fig. 6. Daylight of a residence through the daytime

4.2 Simulation of Daylight of a Roof

The amount of insolation of a roof can be checked by applying this simulator.

A roof and the hip of a roof are newly added to the type of a cell. Furthermore, the information on an amount of insolation is added to the state of a cell. The amount of insolation refers to METPV-3 [4].

METPV-3 is a database of insolation in Japan. It has data of various amounts of insolation (such as amount of global solar radiation (the sum of direct sunlight and skylight), the amount of insolation which enters into a slope) in each area.

Fig.7 is the example of a roof used for the simulation. Since an amount of insolation changes with the angles of direction of a roof, it changes a color. The roof on which a color is different is considered that the type of a cell is also different.

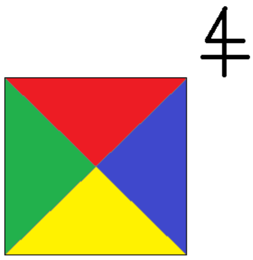

Fig. 7. The example of a roof

Light goes straight on until it strikes upon the hip of a roof. In the roof through which light passed, the amount of global solar radiation is added to the cell which light passed. Moreover, the amount of insolation of skylight is added to the roof through which light did not pass.

Fig. 8 is the simulation result of the amount of insolation of a roof. Table 1 is a setup of a simulation. This figure shows the place with many amounts of insolation more brightly.

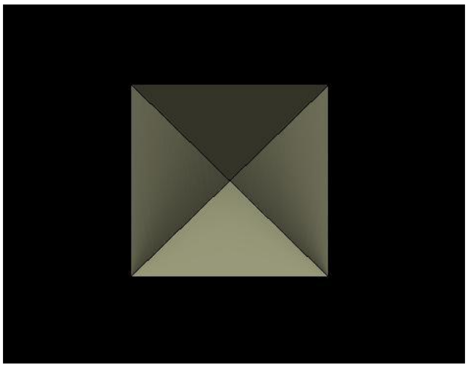

Fig. 8. The amount of insolation of a roof

Table 1. Setup of a simulation

Area	Tokyo
Date	Mid-March
Weather	Shine
A Cell Size	0.01 [m^2]
The angle of gradient of a roof	30°

The fault of this simulation is that the amount of insolation of the top of a roof is smaller than the actual condition. It is necessary to improve by setting up the information such as height.

Fig. 9 is a calculation result of the amount of insolation of the roof of each time. Since the amount of insolation of the roof facing east and west become the maximum around 10:00 and 14:00, respectively, that influence appears in this graph.

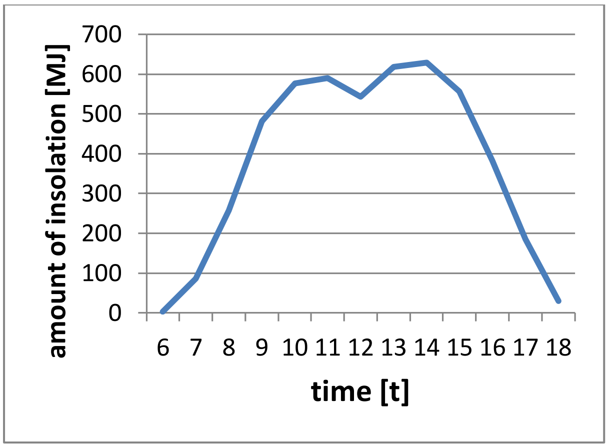

Fig. 9. The amount of insolation of each time

If a part with many amounts of insolation is known, it will be made to reference when performing the simulation such as a photovoltaic generation.

5 DISCUSSIONS

A conventional simulator needs the detailed information on a residence to calculate internal brightness. However, this simulator requires only a floor plan diagram because it does not calculate brightness.

Additional advantage of the simulator comes from the cellular automata model. Because cellular automata can express another new phenomenon easily by adding a new transition rule, the simulator in principle could estimate the room temperature. Since the current simulator could not involve air circulation, it cannot estimate the temperature.

We consider the simulation of a photovoltaic generation as an application of this simulator. The electricity generated of photovoltaic generation is calculable if an amount of insolation is known. If the electricity generated can be predicted only from one image, the advantage of not needing special knowledge will be made. Moreover, a simulation including an atmospheric state (for example, the simulation in the situation where snow lies on the roof) is also considered by using cellular automata.

6 CONCLUSION

A solar insolation simulator is introduced incorporating cellular automata. Simulations demonstrated that the simulator can estimate daylight of a residence using a floor plan diagram.

The simulator could also estimate the amount of insolation of a roof.

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