Simulating the Spread of Ebola based on Cellular Automaton Model

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Abstract. To eradicate Ebola and reduce the current strain, we simulate the spread of it based on cellular automaton to obtain the spread regularity to control the outbreak and reduce death in time. We establish a basic SEIR model at first, base on which we extend the model with a cellular automaton-based approach. We set a susceptible into a cellular and simulate the contact of people in the Extend Moore Neighborhood, in which the contact is more consistent with the reality. Afterwards, we define the initial value of cellular automaton and obtain the spread characteristics of Ebola. To validate our model, we collect data of Western Area of Sierra Leone to simulate and find it performs well.

1. Introduction

With the largest and most complex Ebola outbreak in West Africa currently, more and more people focus on the acute, serious illness which is often fatal if untreated. There have been more cases and deaths in the outbreak and it also spread between countries even all over the world if remains uncontrolled. In order to eradicate the current strain of Ebola even the virus itself, we build a mathematic model which simulate the spread of the disease based on cellular automaton and analyze its regularity.

2. Model for Spread of Ebola

2.1 The basic SEIR model

To study the spread characteristics of Ebola, we employ the SEIR model, which can predict the various properties of the pathogen spread such as the prevalence and the duration of the epidemic. With the help of the model, we can also predict possible outbreaks and bring them under control in further discussion.

The population is divided into four epidemiological categories: susceptible, exposed (in incubation period) , infectious, removal(including recovered and death). To simplify the problem, we can neglect the natural birth, death and migration situation, thus there are $S+E+I+R=N$, where N is a constant. The structure chart is as following:

From the chart we have the model:

$$\begin{cases} \dfrac{dS}{dt} = -\alpha SI \\ \dfrac{dE}{dt} = \alpha SI - \beta E \\ \dfrac{dI}{dt} = \beta E - \gamma I & t \in [0, T] \\ \dfrac{dR}{dt} = \gamma I \\ t = 0: S = S_0, E = E_0, I = I_0, R = R_0 \end{cases} \tag{1}$$

Where T is the spread time of Ebola, and S_0, E_0, I_0, R_0 is the initial number of susceptible, exposed, infectious and removal individuals respectively.

Fig. 1 Structure chart of SEIR model [1]

2.2 Model analysis

The basic SEIR model clearly illustrates the process of the spread of epidemics, and provide a simply and effective method for us to analysis Ebola. However, there are some weakness:

- Contagious condition in SEIR model is uniform contact, which is not consistent with people's activity and social relations in reality.
- It is not easily to add manual intervention such as isolating the patient into SEIR model
- The algorithm will be very complex and difficult to solve if we take some necessary factors such as age structure etc. in to consideration.

For the propose of analyzing the spread characteristic of Ebola more realistic, we determine to develop the cellular automaton model to simulate Ebola spread in terms of the basic SEIR theory.

2.3 Cellular Automaton [2]

A cellular automaton is a discrete model that describes the time development of a system. it treats time as a discrete variable. The model requires an initial configuration and a set of laws that determine how the system develops. At every time step, the cellular automaton advances incrementally and all the laws are implemented.

Table 2 Symbols and Definitions

Symbols	Definitions
t	Time (take day as unit)
i	abscissa in grid space
j	ordinate in grid space
$C_{i,j}$	Cellular which coordinates is (i, j)
$S_{i,j}^{t}$	The status of Cellular (i, j) at time t
$S_{i,j}^{t+1}$	The status of cellular (i, j) at time $t+1$
$P_{i,j}^{t}$	The infected probability of cellular (i, j) at time t
p	The infectious probability
q	The isolated probability
γ	The recovered probability
T_1	The period of incubation
T_2	The period of infectious
T_3	The period of isolated
t_2	Time since the cellular turn into infectious period
t_3	Time since the cellular turn into isolated period

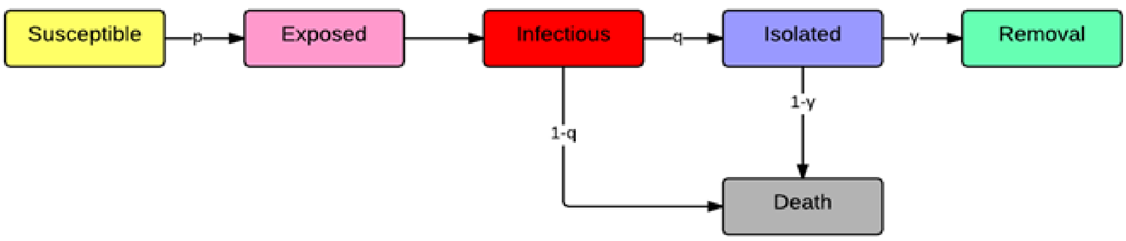

Figure 2 the new structure chart

According to the principle of SEIR, we add the isolated period into the model and we can obtain the new SEIIR model structure chart as Figure 2:

In terms of Figure 2, we develop the cellular automaton model as following:

1. Cellular: The population of a epidemic city.
2. Cellular space: $N = n \times n$, two-dimensional space
3. Neighbor form: Employ the Moore type which neighbor radius is 1 and there are 8 cells around a cellular as its neighbors.

To optimize the model to confirm to the realistic individual's activity (take the contact outside the neighborhood into consideration), we extend the traditional Moore Neighborhood[3] .

Based on the extend Moore Neighborhood, we describe individual's activity through the Random Walk Cellular Automaton method.[3]

4. Time: We define the whole time we study the spread of Ebola as T and take day as the basic unit.

5. Status update rules: We numerical the status of cellular (i, j) by $S_{i,j}^{t}$ at time t and adopt number 0,1,2,3,4,5 to represent the five period in Figure 2.We determine cellular status update rules as following:

- Regard all cellular as susceptible at the beginning, namely they are at status $S_{i,j}^{t} = 0$. Then choose 0.2% cellular as the initial exposed individuals which status $S_{i,j}^{t+1} = 1$ and 0.2% cellular as the initial infectious individuals which status $S_{i,j}^{t} = 2$.
- While $S_{i,j}^{t} = 0$, cellular $C_{i,j}$ is in susceptible period, simulating the cellular $C_{i,j}$ contact with the other cellular in neighborhood and calculate the infectious probability $P_{i,j}^{t}$ which determine the next status of $C_{i,j}$. If the cellular turn into the incubation period, $S_{i,j}^{t+1} = 1$; otherwise, the cellular remains susceptible, $S_{i,j}^{t+1} = 0$.
- While $S_{i,j}^{t} = 1$, cellular $C_{i,j}$ is in the incubation period and it will turn into infectious period after time T_1.
- While $S_{i,j}^{t} = 2$, cellular $C_{i,j}$ is in the infectious period, it has q probability being isolated. If the cellular turn into isolated period, $S_{i,j}^{t+1} = 3$; otherwise, if $t_2 < T_2$, the cellular remains infectious and infect other cellular in neighborhood, if $t_2 \geq T_2$, the cellular turn into death, $S_{i,j}^{t+1} = 5$.
- While $S_{i,j}^{t+1} = 3$, cellular $C_{i,j}$ is in the isolated period . If $t_3 < T_3$, the cellular has γ probability be recovered and turn into immunity period, $S_{i,j}^{t+1} = 4$; otherwise, $t_3 > T_3$, the cellular cannot be recovered and turn into death, $S_{i,j}^{t+1} = 5$.
- While $S_{i,j}^{t+1} = 4$, cellular $C_{i,j}$ is in the immunity period and remove from spread process of virus, $S_{i,j}^{t+1} = 4$.
- While $S_{i,j}^{t+1} = 5$, cellular $C_{i,j}$ is death and remove from spread process of virus, $S_{i,j}^{t+1} = 5$.

3. Model simulation result

According to Ebola spread process of SEIIR model, we adopt the status update rules above to the extend Moore Neighborhood and simulate Ebola spread by cellular automaton. In order to verify the applicable of our model to reality, we collect data of the Western Area of Sierra Leone total cases from September 1, 2014 to February 4, 2015 from website [4] and compare it with our simulation result as Figure 3:

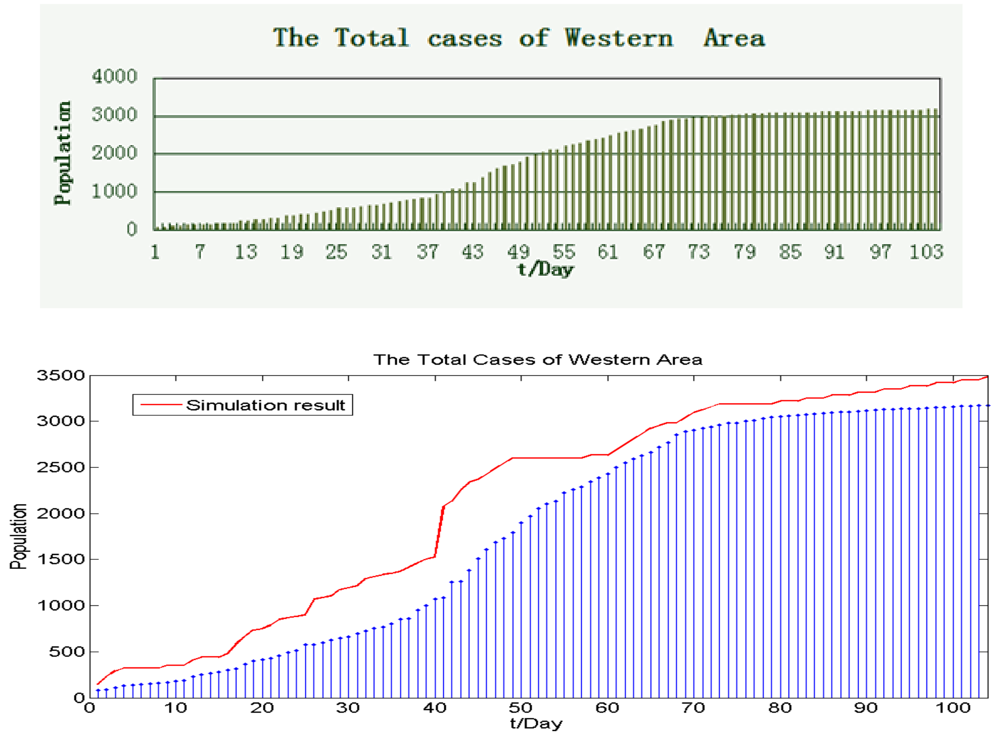

Figure 3 Comparison between simulation result and realistic data

Conclusion: From Figure 3, we can find that the simulation trend is basically consistent with the realistic data of Western Area of Sierra Leone, which demonstrate the applicable of the model to reality.

4. Summary

In this paper, we adopt SEIR method to analyze the spread of Ebola and improve it to SEIIR model which is closer to reality. Based on the theory above, we develop the cellular automaton model and determine the status update rules. Specially, we extend the traditional Moore Neighborhood to optimize the model to confirm to the realistic individual's activity. For the simulation result, we compare it with the data of the Western Area of Sierra Leone which indicate the model performs well.

References

[1] http://international.caixin.com/2014-10-17/100739657.html
[2] Ai Li You. "SIR Epidemic Model Based on Cellular Automata" Journal of Xinjiang University.2010, 27(1): 56-59.
[3] Gang Jia Tai, Dai Qin Wu, Li Shu Juan, Tan Xin XinA "CA-Based Epidemic Model with Isolated Intervention" Journal of Dalian University Vol.35 No.3 Jun. 2014
[4] http://www.mofcom.gov.cn/article/i/jyjl/k/201502/20150200890064.shtml