The COVID-19 SIR Dynamical Prediction Model for Eradicating Corona Virus Disease 2019

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ABSTRACT

This paper has established the COVID-19 SIR Dynamical Prediction Model. First, the official data is devoted to fit and simulate the spread of the epidemic, and the spread of speed of some countries. Then, in the next period of time the number of infected persons and several numerical trends are predicted. Finally, the error of the population infected is calculated and the result is 7.09%. It proposed the solution to solve practical problems.

KEYWORDS

SIR Model, COVID-19, Dynamical Prediction Model.

INTRODUCTION

Corona Virus Disease 2019 (COVID-19) is highly infectious, and has the characteristics of high pathogenicity and high morality. Recently, in some countries, WHO report shows that thousands of people have still been confirmed or suspected to be infected with the COVID-19 virus, which has killed many people. For example, the COVID-19 in M country and G country are also serious outbreak, and the death cases are also concentrated. Therefore, a realistic, sensible, and useful model is established to consider the spread of the disease.

M country has a total population of about 161 million people, and there are about 49.6 million people in G country. In order to describe the process of spreading infection rate, predict the number of infections in the future, and provide the available data for the next treatment prevention, we adopt to study the SIR dynamical prediction model. SIR model[1] is a kind of infectious disease model of international general. Through the model, we calculate the actual results. It also has high feasible degree.

COVID-19 SIR DYNAMICAL PREDICTION MODEL

Assumpt that new variation of the virus will not happen when fighting against the virus, the detected patients are no longer infectious, and using data from the official download are true and reliable. In order to carry out the prevention and monitor the COVID-19 virus, and to study the transmission speed and transmission range, the SIR model is established to predict the future trend of the spread of the virus. Here in M country, for example.

First of all, M country for total N, and there is no change. Neither consider the life and death of the population, nor consider the migration of the population[2].
People can be divided into three types who are healthy subjects, COVID-19 infections and immune out of recovering, which is called SIR model. The proportion of three types of people in the total number of N accounted respectively denoted by \( s(t), i(t) \) and \( r(t) \) [3, 4].

COVID-19 has an incubation period of about 15 days. For COVID-19 infections, the average effective contact infections is constant. The number is \( \lambda \), which is called the contact rate. When COVID-19 infections are in contact with the COVID-19-infected patients effectively, healthy become infected.

The people that be cured of COVID-19-infected persons accounted for the proportion of the total number of patients is a constant \( \mu \) per month, which is called the cure rate. \( 1/\mu \) is the average infectious period of the epidemic. Contact number for the infectious period is \( \sigma = \lambda / \mu \).

By Assumption, 1 is clearly:

\[ s(t) + i(t) + r(t) = 1 \]  \hspace{1cm} (1)

Based on the assumption, each of the COVID-19-infected persons can make \( \lambda N s \) healthy people become patients. Because the number of patients is \( Ni \), so a total of \( \lambda N s i \) healthy people were infected, and \( \mu i \) out of illness COVID-19-infected persons. So, \( \lambda N s i - \mu i \) is the increase number of COVID-19 infections. That is:

\[ N \frac{di}{dt} = \lambda N s i - \mu i \]  \hspace{1cm} (2)

Meanwhile \( \lambda N s i \) is also the reduction of \( Ns \):

\[ N \frac{ds}{dt} = -\lambda N s i \]  \hspace{1cm} (3)

Then remember the initial moment of health and COVID-19-infected persons and the proportion is \( s_0 (s_0 > 0), i_0 (i_0 > 0) \) (Might as well set out of the initial value of SI \( r_0 = 0 \)).

By (1) (2) (3), SIR model equation can be written as:

\[
\begin{align*}
\frac{di}{dt} &= \lambda si - \mu i \\
\frac{ds}{dt} &= -\lambda si
\end{align*}
\]  \hspace{1cm} (4)

Equation (4) cannot calculated the analysis of \( s(t) \) and \( i(t) \). So, we first make numerical calculations.
NUMERICAL CALCULATIONS OF THE MODEL

Data Calculating

By finding the data, we found a M country official monitoring data from the discovery of the epidemic so far[7], as shown in Table I.

| date         | Total cases of the reported daily date |
|--------------|----------------------------------------|
| 4.12-4.21    | 182 182 219 341 266 306 312 492 434 390 |
| 4.22-5.1     | 414 503 309 418 497 549 641 564 571 552 |
| 5.2-5.11     | 665 665 786 790 706 709 636 887 1034 969 |
| 5.12-5.21    | 1162 1041 1202 930 1273 1602 0 1251 1617 1773 |
| 5.22-5.31    | 1694 1873 1532 1975 1166 1541 2029 2523 1764 2545 |
| 6.1—6.10    | 2381 2911 2695 2423 2828 2635 2743 2735 3171 3190 |
| 6.11-6.20   | 3187 3471 2856 3141 3099 3862 4008 3803 3243 3240 |
| 6.21-6.30   | 3531 3480 3412 3463 3946 3868 3504 3809 4014 3682 |
| 7.1-7.10    | 3775 4019 3114 3288 2738 3201 3027 3489 3360 2949 |
| 7.11-7.20   | 2686 2666 3099 3163 3533 2733 3034 2709 2459 2928 |
| 7.21-7.30   | 3057 2744 2856 2548 2520 2275 2772 2960 3009 2695 |
| 7.31-8.9    | 2772 2199 886 1356 1918 2654 2977 2851 2611 2487 |
| 8.10-8.19   | 2907 2996 2995 2617 2766 2644 2024 2595 3200 2747 |
| 8.20-8.23   | 2868 2401 2265 1973 |

Using the data to draw nearly half a year of COVID-19 virus from spreading graph of M country, shown in Figure 1.

Figure 1. M country COVID-19 epidemic dynamics.
To predict the number of people infected with the virus in the next few months, we must first know the value of the contact rate and cure rate. M country contact rate has been changing from the beginning of the epidemic, every 15 days changing circumstances as shown in Table II.

**TABLE II. CHANGES IN THE NUMBER OF PEOPLE INFECTED EVERY 15 DAYS IN M COUNTRY.**

| Date  | Number of people |
|-------|------------------|
| 4/12  | 182              |
| 4/27  | 549              |
| 5/12  | 1162             |
| 5/27  | 1541             |
| 6/11  | 3187             |
| 6/16  | 3862             |
| 7/1   | 3775             |
| 7/16  | 2733             |
| 7/31  | 2772             |
| 8/15  | 2644             |
| 8/23  | 1973             |

As can be seen from the table, In the first month, the contact rate is close to 2. After the timely detection of the outbreak, with the attention of the government and international intervention, every 15 days the increase number of infected people tend to decrease, the value of the contact rate $\lambda$ in May to June for 1/3 to 1/2 of the inter, after June decreased. Visibly, the government taking quarantine measures to control virus outbreak does play a role.

In this model, the actual situation for the simulation of virus transmission will be obtained. In equation (4), set $\lambda = 1, \mu = 0.3, i(0) = 0.000007, s(0) = 0.999993$. A simplified calculation result output with MATLAB is shown in Table III, $i(t), s(t)$ graphics shown in Figure 2. As time increases, $s(t)$ movement from right to left along the track. From Table 3, the growth of $i(t)$ can be seen from the initial value to about $t=18$ when reaches a maximum, and then decrease, $t \to \infty, i \to 0, s(t)$ is monotonically decreasing, $t \to \infty, s \to 0.0411$.

**TABLE III. THE NUMERICAL RESULTS OF $i(t), s(t)$.**

| t    | 0         | 1         | 2         | 3         | 4         | 5         |
|------|-----------|-----------|-----------|-----------|-----------|-----------|
| $i(t)$ | 0.000007  | 0.000014  | 0.000028  | 0.000056  | 0.0001    | 0.0002    | 0.0005    |
| $s(t)$ | 0.999993  | 0.999983  | 0.999982  | 0.999922  | 0.9998    | 0.9997    | 0.9993    |
| t    | 7         | 8         | 9         | 10        | 11        | 12        | 13        |
| $i(t)$ | 0.0009    | 0.0019    | 0.0038    | 0.0075    | 0.0149    | 0.0290    | 0.0550    |
| $s(t)$ | 0.9987    | 0.9973    | 0.9946    | 0.9893    | 0.9787    | 0.9581    | 0.9198    |
| t    | 14        | 15        | 16        | 17        | 18        | 19        | 20        |
| $i(t)$ | 0.0994    | 0.1646    | 0.2412    | 0.3057    | 0.3367    | 0.3317    | 0.3011    |
| $s(t)$ | 0.8529    | 0.7485    | 0.6111    | 0.4640    | 0.3354    | 0.2393    | 0.1748    |
| t    | 21        | 22        | 23        | 24        | 25        | 26        | 27        |
| $i(t)$ | 0.2596    | 0.2163    | 0.1763    | 0.1413    | 0.1120    | 0.0882    | 0.0690    |
| $s(t)$ | 0.1322    | 0.1041    | 0.0853    | 0.0728    | 0.0642    | 0.0581    | 0.0537    |
| t    | 28        | 29        | 30        | 31        | 32        | 33        | 34        |
| $i(t)$ | 0.0538    | 0.0419    | 0.0325    | 0.0252    | 0.0195    | 0.0151    | 0.0117    |
| $s(t)$ | 0.0505    | 0.0482    | 0.0465    | 0.0452    | 0.0442    | 0.0435    | 0.0429    |
| t    | 35        | 36        | 37        | 38        | 39        | 40        | 41        |
### Data Fitting

We analyze changes of \(i(t)\) in order to determine the total number of infected people. Then, we use MATLAB for data fitting: time variable \(t\) as the independent variable (134 days), infections \(N_i\) as the dependent variable, and a name for each group of data respectively. Through trial and analysis to know, because of the number of infected patients showed a trend of rapid outbreak of the COVID-19 virus status, it is more appropriate to use Gaussian functions to fit. Using the model SIR to calculate the spread of the virus SIR trend data obtained, the number of infected persons fitting the different periods of time as a function below:

\[
m(t) = -2628e^{-((t-102.7)/25.73)^2} + 5313e^{-((t-96.1)/50.68)^2};
\]

That is:

\[
m(t) = -2628e^{-\frac{(t-102.7)^2}{25.73}} + 5313e^{-\frac{(t-96.1)^2}{50.68}}. \tag{5}
\]

Using the model fitting process and the establishment of the above, the COVID-19 virus development of M country is obtained. To find the goodness of the model we see with the real historical data, and get the results as shown. Similarly, given the change of the number of the infected function in G country with the higher number of 11541 infected persons on August 23 as follows:

\[
g(t) = 1154e^{-((t-114)/3.677)^2} + 13910e^{-((t-157.9)/65.74)^2};
\]

That is:

\[
g(t) = 1154e^{-\frac{(t-114)^2}{3.677}} + 13910e^{-\frac{(t-157.9)^2}{65.74}}. \tag{6}
\]
Figure 3 shows the simulation renderings spread of the virus over time (horizontal axis per unit of meaning for 15 days) in M country and G country.

![Figure 3. The COVID-19 spread simulation renderings of M country and G country.](image)

**Error Analysis**

We can see the SIR model simulation results on the map of M country. There is a large degree of agreement, especially about the first month's trends with real data. This agreement can be specifically reflected by the following several sets of data in Table IV.

| Time | 4.12 | 4.26 | 5.9 | 5.22 | 6.4 | 7.1 | 7.14 | 7.27 |
|------|------|------|-----|------|-----|-----|------|------|
| Fitting data | 157 | 393 | 854 | 1614 | 2607 | 3579 | 2956 | 2513 |
| The actual data | 182 | 418 | 887 | 1694 | 2423 | 3775 | 3163 | 2772 |

Comparison of the data in the table, the error can be obtained as follows:

- \( \frac{157 - 182}{182} \approx -13.7\% \)
- \( \frac{393 - 418}{418} \approx -5.98\% \)
- \( \frac{854 - 887}{887} \approx -3.72\% \)
- \( \frac{1614 - 1694}{1694} \approx -4.72\% \)
- \( \frac{2607 - 2423}{2423} \approx 7.59\% \)
- \( \frac{3579 - 3775}{3775} \approx -5.19\% \)
- \( \frac{2956 - 3163}{3163} \approx -6.54\% \)
- \( \frac{2513 - 2772}{2772} \approx -9.34\% \)

It has been observed that the average error is 7.09\%. Error is less than 10\%. Therefore, we can say that the COVID-19 infection SIR model truly reflects the current situation in M country spread of the virus. Thus, we can use the number of infected persons fitting function formula of COVID-19 to predict specific number of infections in the next several units (15 days) in M country and G country[6]. We should provide the necessary preparations for the production of vaccine demand forecasting, in order to achieve timely detection, early
prevention and control purposes, and ultimately control the COVID-19 virus in all mankind poison.

**TABLE V. DATA FORECAST OF M COUNTRY.**

| Time (15 days) | 9.21 | 10.6 | 10.21 | 11.5 | 11.20 | 12.20 | 2021.1.19 |
|---------------|------|------|-------|------|-------|-------|-----------|
| The number of infected persons in M country | 919 | 389 | 137 | 41 | 10 | 0.36 | 0.05 |
| Time (15 days) | 9.21 | 10.6 | 10.21 | 11.5 | 11.20 | 12.20 | 2021.1.19 |
| The number of infected persons in G country | 13826 | 12668 | 10459 | 7782 | 5217 | 1716 | 842 |

Comparison of the data in Table V indicates the trends can be obtained as follows. The situation will be eased in M country until the infections disappear. The number of infections will peak in September or October and then drop in G country. Figure 4 is $i~s$ graph, known as the phase trajectory[5] of the COVID-19 SIR dynamical prediction model.

![Figure 4. $i~s$ graph.](image)

**CONCLUSION**

We use the SIR model when predicts the change of infections. Without considering the population birth, death, to moving in and out of the population of the COVID-19 virus, the model have some limitations. However, SIR model fully considers the incubation period of the spread of the virus, which could get the basic reproductive number of the disease extinction and continued survival. The model studies the existence condition of the different conditions of various kinds of balance threshold, and determine the terms of the stability of the equilibrium point. Meanwhile, the model also studied saturated incidence rate and recovery rate and won the key parameters of the spread of the disease, the basic reproductive number and all kinds of balance condition of the existence of threshold.

The established model describes the communication process, analysis of the rules of change of the number of infections, infectious disease prediction climax time measurement, the spread of infectious diseases and to explore the means and measures the degree to stop the spread of the virus. But the Weakness is that it does not consider the virus variation, and the approximate data guide a small error. In future, the quantity of the medicine needed, possible feasible delivery...
systems, speed of manufacturing of the vaccine or drug, and any other critical factors can still be considered necessary to optimize the eradication of COVID-19, or at least its current strain.

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