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Optimal models for estimating future infected cases of COVID-19 in Oman

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Abstract

The recent coronavirus disease 2019 (COVID-19) outbreak is of high importance in research topics due to its fast spreading and high rate of infections across the world. In this paper, we test certain optimal models of forecasting daily new cases of COVID-19 in Oman. It is based on solving a certain nonlinear least-squares optimization problem that determines some unknown parameters in fitting some mathematical models. We also consider extension to these models to predict the future number of infection cases in Oman. The modification technique introduces a simple ratio rate of changes in the daily infected cases. This average ratio is computed by employing the rule of Al-Baali [Numerical experience with a class of self-scaling quasi-Newton algorithms, JOTA, 96 (1998), pp. 533–553], in a sense to be defined, for measuring the infection changes.

Keywords: COVID-19, forecasting, data fitting models, least-squares problem, forecasting, unconstrained optimization methods.

1. Introduction

The coronavirus disease 2019 is an infectious disease that first began in Wuhan in the Hubei Province, China, on December 31, 2019, and rapidly spread throughout the city. Then, after 31st January 2020, the World Health Organization (WHO) declared the outbreak of COVID-19 to be a pandemic after it spread globally [3].

Many researchers have studied the outbreak of COVID-19 (see, e.g., Almeshal et al. [3], Ayoub et al. [4], Batista [5], and the references therein) to provide a prediction of the number of infections that will occur over time globally and when the spread of the virus end. Batista [5] investigated the logistic and classic susceptible-infected-recovered dynamic model to predict the daily cases and used the iterated Shanks method to obtain the final numbers of the coronavirus epidemic. Based on the confirmed data on COVID-19 in Kuwait, Almeshal et al. [3] estimated the size of the COVID-19 spread and determined its end phase. Xavier [15] fit the daily total cases of COVID-19 to the logistic model of the least-squares with application of the steepest descent method. Garbey et al. [8] used a computational model to construct a

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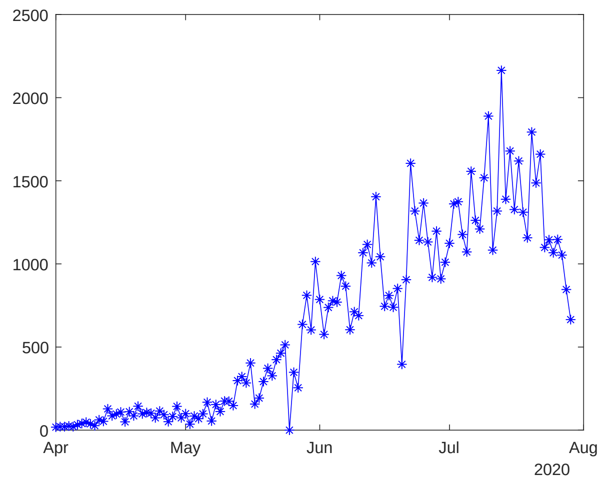
hospital workflow during a pandemic and to assist the management of the health system facing a new crisis.

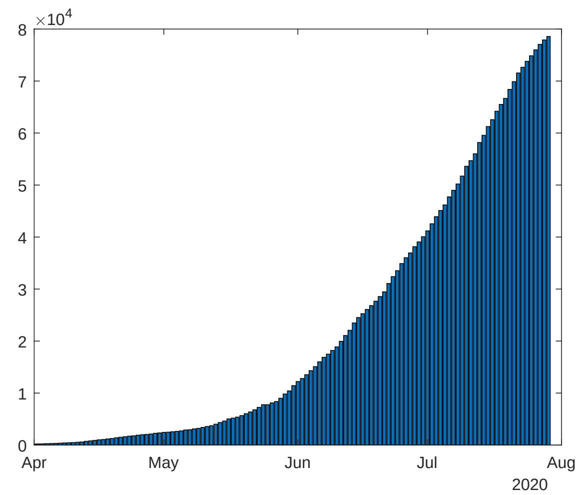
Oman, with a total population of less than five million [13], also faced the new epidemic of COVID-19 and reported that the first two returning citizens from Iran tested positive for COVID-19 on February 24, 2020 [11] and were placed under domestic quarantine. By the end of March, Oman had entered the community transmission stage of COVID-19, and closed its border. The first death in Oman was recorded in April, 2020, and the lockdown measures and social distancing rules were initially imposed in the capital city of Muscat from April 10 to 22. By May 2, COVID-19 outbreak had spread to all of Oman, the lockdown measures were extended until the end of May. The daily new cases over 1000 were recorded throughout July, and the second lockdown measures and night time curfew were then imposed until August 8. In Table 5 of the appendix, we list the numbers of daily reported cases, recovery cases, death cases, and the accumulated cases for COVID-19, in Oman during the period from April 1 to July 29, 2020. We observe that on July 29, the total cases of COVID-19, recovery and death are 78569, 60240 and 412, respectively. These confirmed data, which were taken from the websites in [11] and [14], will be used to define some parameters in the optimal models to estimate the number of future cases.

In this paper, we define the infected data $(t_i, y_i), i = 1, 2, \ldots, 120$, which are stated in the first and second columns of Table 5, to illustrate our analysis that can be extended to other data. To provide an idea of the infected daily cases in Oman, we plot the given data (the daily reported infected cases) and join each two points, in that order, by a straight line as depicted in the left of Fig. 1. The right histogram of Fig. 1 shows the cumulative cases for the period of four months.

In our analysis we predict the daily new cases of the COVID-19 epidemic in Oman, based on deriving some mathematical models, nonlinear least-squares problems, and average ratio measures. In Section 2, we derive a nonlinear least-squares problem for a certain type of models that depend on the available data. Using the infected cases in Oman, given in Table 5, we define the parameters that appear in the proposed models by solving the corresponding least-squares problems. Section 3 proposes the average ratio measure and uses it to modify some models in forecasting the future infected cases. Section 4 concludes the paper and Appendix provides the data on COVID-19 that were recorded in Oman.



(a) Daily infected cases



(b) Cumulative infected cases

Figure 1: Infected cases of COVID-19 in Oman from April 1 to July 29, 2020.

2. Data Fitting Models and Least-Squares Problem

In this section, we consider the following form of a mathematical model:

$$y(t) = \phi(x, t), \tag{2.1}$$

where $x = (x_1, \dots, x_n)^T$ is a vector parameter of length n, defined by the user and based upon the model applications (here, $2 \leqslant n \leqslant 4$). It is assumed that the function ϕ is continuous and differentiable for both x and t.

A value for x is to be found in a certain sense using a given available data $(t_i, y_i), i = 1, 2, \dots, l$, $(l \geqslant n)$ (as in Table 5, for instance) such that the following residuals or the Euclidean norm $\|r(x)\|$, where $r(x) = (r_1, r_2, \dots, r_l)^T$ are sufficiently close to zero:

$$r_i(x) = y_i - \phi(x, t_i), \qquad i = 1, 2, \dots, l. \tag{2.2}$$

Thus, we consider finding the least value of the function $f(x) = \frac{1}{2}\|r(x)\|^2$ by solving the unconstrained optimization problem

$$\min_x f(x) = \frac{1}{2}\sum_{i=1}^{l}[r_i(x)]^2 = \frac{1}{2}r(x)^T r(x) \tag{2.3}$$

that is known as the Least-Squares Problem (LSP), because the objective function $f(x)$ is the sum of squared residuals. An iterative algorithm will be used to solve this problem provided a starting point $x^{(1)}$ is given.

To obtain a solution of problem (2.3) (say, x^*), we must solve the system of n equations $g(x) = 0$, where

$$g(x) = \nabla f(x) = \sum_{i=1}^{l} r_i(x)\nabla r_i(x) = A(x)r(x) \tag{2.4}$$

is the gradient of f and

$$A(x) = \nabla r(x)^T = -[\nabla\phi(x, t_1), \nabla\phi(x, t_2), \dots, \nabla\phi(x, t_l)]$$

is the Jacobian matrix of the residual vector r. If $\phi(x, t)$ is a linear combination of x, and from (2.2), so dose all the residuals, then A is reduced to a constant matrix and $g(x) = 0$ to the so-called system of normal equations

$$(AA^T)x = -A\hat{y},$$

where $\hat{y} = (y_1, y_2, \dots, y_l)^T$, which needs to be solved to obtain the solution x^* (see, e.g., Burden and Faires [6]). In general, the residual $r(x)$ is nonlinear so that solving the system $g(x) = 0$ analytically might be impossible. Thus, we consider solving problem (2.3) using a numerical optimization method that generates a sequence of points $\{x^{(k)}\}$ iteratively, which converges to x^* for a certain initial estimate $x^{(1)}$ (for details, see, e.g., Madsen, Nielsen and Tingleff [10]). Here, we consider applying the line search descent method (for a description, see, e.g., Fletcher [7], Hansen, Pereyra and Scherer [9], Madsen, Nielsen and Tingleff [10] and Nocedal and Wright [12]).

We now define some least-squares data fitting problems based on selecting certain mathematical models of form (2.1) from the literature. In particular, we consider the following five models with given starting points:

$$\phi_1(x,t) = x_1 + x_2 t, \qquad x^{(1)} = (1,1)^T \tag{2.5}$$

$$\phi_2(x,t) = x_1 + x_2 t + x_3 t^2, \qquad x^{(1)} = (1,1,1)^T \tag{2.6}$$

$$\phi_3(x,t) = x_1 + x_2 t + x_3 t^2 + x_4 t^3, \qquad x^{(1)} = (1,1,1,1)^T \tag{2.7}$$

$$\phi_4(x,t) = x_1 + x_2 e^{-x_3 t}, \qquad x^{(1)} = (1,1,0.1)^T \tag{2.8}$$

$$\phi_5(x,t) = \frac{x_1}{x_2 + x_3 e^{-x_4 t}}, \qquad x^{(1)} = (1,1,1,0.1)^T. \tag{2.9}$$

Note that ϕ_i, for $i = 1,2,3$, represents the linear least-squares problems (eg., [6], [10]), while ϕ_4 and ϕ_5 the the nonlinear least-squares problems of form (2.3) (e.g., [10]). The corresponding five models (referred to as $LSP_i, i = 1,2,\ldots,5$, respectively) are applied to predict the daily infected cases of COVID-19 in Oman, using the confirmed data given in Table 5, where t_i denotes the number of day i, y_i is the number of infected cases on day i, and $l = 120$. To solve these problems, we used the well-known BFGS quasi-Newton optimization method (described in Fletcher [7]) and obtained, for each problem, a solution x^*, the optimal value $f(x^*)$, and the norm $\|g(x^*)\|$, as listed respectively in the second, third, and fourth columns of Table 1, rounded to four significant figures. We also listed the number of iterations (Iter) and the function and gradient (f,g) calls, which are required to solve the problems. Because all values of $f(x^*)$ are large, the problems are usually referred to large residual.

Table 1: Solutions of $LSP_i, i = 1,2,\ldots,5$

Problem	x^*	$f(x^*)$	$\|g(x^*)\|$	Iter	f, g calls
LSP_1	$(-208.90, 14.19)^T$	3.735×10^6	3.592×10^{-7}	6	7, 6
LSP_2	$(-168.4, 12.20, 0.01646)^T$	3.716×10^6	3.725×10^{-8}	5	9, 5
LSP_3	$(218.6, -25.41, 0.7902, -0.004263)^T$	2.555×10^6	2.360×10^{-5}	7	15, 7
LSP_4	$(-7763, 7583, -0.001688)^T$	3.722×10^6	7.608×10^{-1}	119	173, 146
LSP_5	$(8.542, 0.006307, 0.9231, 0.07849)^T$	2.692×10^6	10.76	33	107, 66

Substituting the five values of x^*, from the second column of Table 1 for $LSP_i, i = 1,2,\ldots,5$, into expressions (2.5), (2.6), ..., (2.9), respectively, we obtain the following five (new) mathematical models:

$$y = \phi_i^*(t) = \phi_i(x^*, t), \tag{2.10}$$

for $i = 1,2,\ldots,5$. In Fig. 2 we plot the results and compare them with the data as given in Fig. 1(a). It indicates that our models seem to fit reasonably well with the available 120 data for the period of April 1 to July 29, 2020. From the extended period (from July 29, 2020) to August 31, 2020 in Fig. 2, we note that the predicted daily number of infected cases decreases only for LSP_3, and observed that the peak of the epidemic was probably on July 15, 2020. Furthermore, the end of the outbreak is expected to be at the end of August 2020.

However, since the other models for LSP_i do not predict a decrease in the number of infected cases, in the next section we modify (2.10) based on the new average ratio measure to improve the estimated future infected cases.

3. New Average Ratio Measure and Modified Models

There are several possible choices for defining the rate of changes to analyze the short-term forecasting. We consider the rule of Al-Baali (see, e.g., [2] and essentially [1]) for measuring the ratio of changes. This rule is defined using the average of the ratios $R_i \in [0,\ 2]$, $i = p, p+1, \ldots, q-1$, for the range $[p, q]$ as follows:

$$R = \frac{1}{q-p} \sum_{i=p}^{q-1} R_i, \tag{3.1}$$

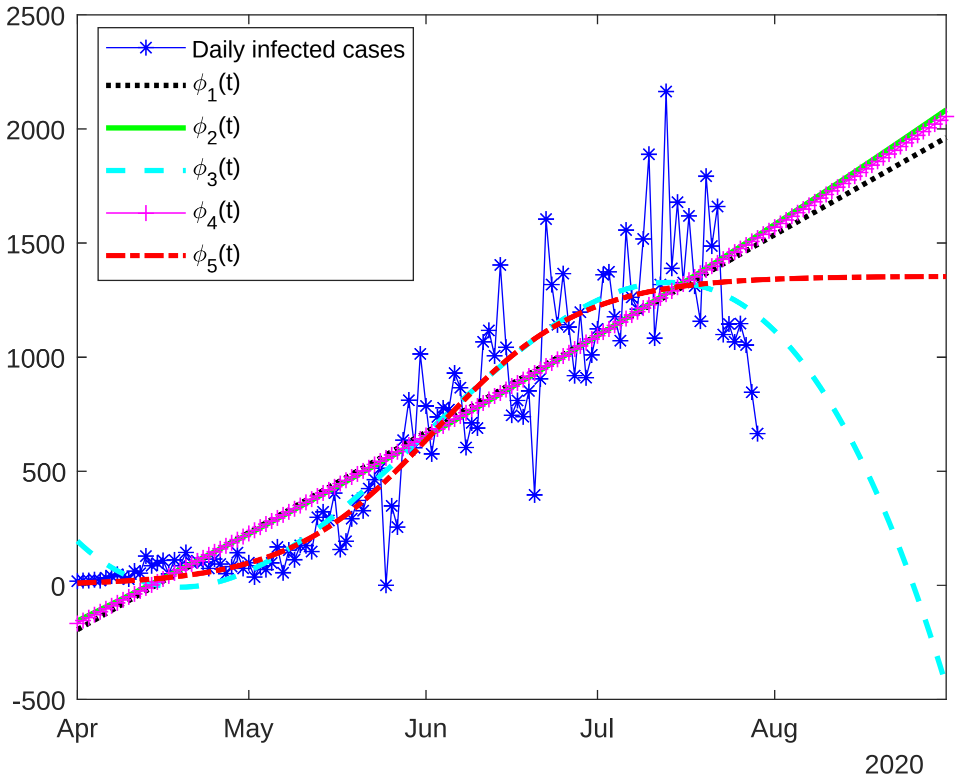


Figure 2: Fitting daily infected cases and solution of $LSP_i, i = 1, 2, \ldots, 5$.

Here, p and q are the first and last numbers in the given daily reported infected cases and R_i is given by

$$R_i = \begin{cases} \dfrac{y_{i+1}}{y_i} & \text{if} \quad y_{i+1} \leqslant y_i \neq 0 \\ 2 - \dfrac{y_i}{y_{i+1}} & \text{if} \quad y_{i+1} > y_i \\ 1 & \text{if} \quad y_{i+1} = y_i = 0, \end{cases} \tag{3.2}$$

where y_i and y_{i+1} are the number of infected cases on day i and next day, respectively (for COVID-19 in Oman as reported and listed in Table 5). The average value of ratio R (3.1) always falls in the interval $[0, 2]$. A value of $R \leqslant 1$ indicates that there is a 100(1-R)% chance of reducing the daily number of infected cases. Otherwise, when $R > 1$, there is a 100(R-1)% chance of increasing the number of infected cases (for more details on this measurement ratio, see Al-Baali [2], for instance).

Since the incubation period of COVID-19 can be as long as 14 days, the WHO states that the clinical recovery time for mild infected cases is approximately 2 weeks. Thus, isolation and quarantine should be in place for 14 days for an infected person. For models application of the outbreak of COVID-19 in Oman, we choose two periods of 15 days and 30 days to obtain the values of R.

For $q = 120$ and $p = 1, 16, 31, 46, 61, 76, 91$, and 106, we obtained the values of R for a period of 15 days as stated in the last column of Table 2. The first column of the table listed the total number of the days for 8 periods of time as stated in the second column. We observe that when the value of ratio R is closed to 1, a slight change in the future infected cases is expected, but for $R = 0.9402$, a reduction in the predicted future new infected cases is expected. Instead of (2.10), the following modified models for forecasting the

Table 2: Value of R for different days

Number of days	Day, Period	R
120	1–120, April 1 - July 29, 2020	1.024
105	16–120, April 16 - July 29, 2020	1.016
90	31–120, May 1 - July 29, 2020	1.02
75	46–120, May 16 - July 29, 2020	1.009
60	61–120, May 31 - July 29, 2020	0.9924
45	76–120, June 15 - July 29, 2020	0.9895
30	91–120, June 30 - July 29, 2020	0.9880
15	106–120, July 15 - July 29, 2020	0.9402

COVID-19 will be used to estimate the future number of infected cases:

$$y(t) = \begin{cases} \phi_i(x^*, t) & \text{if} \quad t \leqslant t_a, \\ \phi_i(x^*, t_a) R^{t-t_a} & \text{if} \quad t > t_a, \end{cases} \tag{3.3}$$

for $i = 1, 2, \ldots, 5$ and $t_a = 120$ is the number of days corresponds to the last data entry that is on July 29, 2020.

To illustrate the behaviour of the modified five models (2.10), we consider the eight periods of 15 days as listed in the first column of Table 2 and predict the future number of infected cases up to August 31, 2020, where $t = 121, 122, \ldots, 153$ (which corresponds to the period of July 30 - August 31, 2020). The expected results are listed in Table 4.

We note that the modified functions ϕ_3 and ϕ_5 estimate the future infected cases better than the other modified functions in the sense that their predicted future cases are less than that of the other prediction regardless whether $R > 1$ or $R < 1$. In addition, ϕ_3 seems to give a little better estimate than ϕ_5. For example, using $R = 0.9402$, the former function ϕ_3 prediction less number of infected cases for the future 32 days (from July 29, 2020) from 1111 to 154, while the latter function ϕ_5 from 1258 to 175. Furthermore, the predicted future numbers of infected cases of ϕ_3 for $R = 0.9924$ and $R = 0.9402$ are decreasing from 1173 and 1111 to 919 and 159, respectively. The difference between the final predicted two numbers of cases is large, although the corresponding difference in R is very small. The predicted results are very encouraging, since following the second lockdown which eventually lifted by the end of the first week of August, the daily number of infected cases in Oman have consistently dropped to below 200 until the end of August 2020.

To illustrate these results, we sketch the five models (3.3) from the period of April 1 – October 30, 2020 as shown in Fig. 3. We observe that from Fig. 3(d) where the value R=0.9402 is obtained for the period of July 15 to July 29, 2020, the peak (daily) number of infected cases is nearly 1400, and after that, the outbreak of COVID-19 in Oman vanishes by the mid of October 2020.

For comparison (in the worst case scenario), we also consider a longer monthly period of infected cases to obtain the values of R. The results are listed in Table 3 for the four months of April, May, June, and July. We calculate the largest value of $R = 1.075$ for May, and the smallest values of $R = 0.9840$ for July. The predicted results are expected to progressively change every month starting from April.

The corresponding modified function (3.3) with the new values of R and $t_a = 30, 61, 91$, and 120, which is the number of days corresponding to the last available data on April, May, June, and July, respectively are plotted in Fig. 4. We note from Fig. 4(a-c) that the values of $\phi_i, i = 1, 2, \ldots, 5$, for the four cases of $R > 1$, increase as t increases. However, for $R < 1$, they decrease as t increases (see Fig. 4(d)).

As illustrated in Fig. 4, the predicted of infected cases in Oman are progressively changing according to the monthly values of R. Fig. 4(a) shows using R=1.032 for the month of April, the predicted cases are increasing to 1400 by the end of June. We note that for the month of May, the value of R increases to R=1.075, and accordingly as shown by Fig. 4(b), the predicted number of cases is sharply increasing to 50000 by the end of July. For the month of June, we notice that, the value of R decreases to R=1.004, and as shown in Fig. 4(c), after a steady increase up to the end of July, the predicted cases are slowing down to 1300 by the end of August. Lastly for the month of July, the value of R decreases again to R=0.9840, and Fig. 4(d) shows after a steady increase up to the end of August, the predicted cases are falling sharply to below 800 by the end of September, and the number continues to drop to below 400 by the end of October 2020.

Table 3: Value of R for a period of monthly cases

Number of days	Day, Period	R
30	1–30, April 1-30	1.032
31	31–61, May 1-31	1.075
30	62–91, June 1-30	1.004
29	92–120, July 1-29	0.9840

Table 4: Predicted COVID-19 cases in Oman from July 30 - August 31, 2020.

	$R = 1.024$					$R = 1.009$				
Day\ ϕ_i	ϕ_1	ϕ_2	ϕ_3	ϕ_4	ϕ_5	ϕ_1	ϕ_2	ϕ_3	ϕ_4	ϕ_5
30-Jul	1530	1569	1210	1559	1371	1507	1546	1192	1536	1351
31-Jul	1566	1607	1239	1597	1403	1521	1560	1203	1550	1363
1-Aug	1604	1646	1269	1635	1437	1535	1574	1214	1564	1375
2-Aug	1643	1685	1299	1674	1472	1548	1589	1225	1578	1387
3-Aug	1682	1726	1331	1714	1507	1562	1603	1236	1592	1400
4-Aug	1722	1767	1363	1755	1543	1576	1617	1247	1607	1412
5-Aug	1764	1809	1395	1798	1580	1591	1632	1258	1621	1425
6-Aug	1806	1853	1429	1841	1618	1605	1647	1270	1636	1438
7-Aug	1849	1897	1463	1885	1657	1619	1661	1281	1651	1451
8-Aug	1894	1943	1498	1930	1697	1634	1676	1293	1665	1464
9-Aug	1939	1989	1534	1976	1737	1649	1691	1304	1680	1477
10-Aug	1986	2037	1571	2024	1779	1663	1707	1316	1695	1490
11-Aug	2033	2086	1609	2073	1822	1678	1722	1328	1711	1504
12-Aug	2082	2136	1647	2122	1866	1694	1737	1340	1726	1517
13-Aug	2132	2187	1687	2173	1910	1709	1753	1352	1742	1531
14-Aug	2183	2240	1727	2225	1956	1724	1769	1364	1757	1545
15-Aug	2236	2294	1769	2279	2003	1740	1785	1376	1773	1559
16-Aug	2289	2349	1811	2333	2051	1755	1801	1389	1789	1573
17-Aug	2344	2405	1855	2389	2100	1771	1817	1401	1805	1587
18-Aug	2401	2463	1899	2447	2151	1787	1833	1414	1821	1601
19-Aug	2458	2522	1945	2506	2202	1803	1850	1427	1838	1616
20-Aug	2517	2582	1991	2566	2255	1819	1867	1439	1854	1630
21-Aug	2578	2644	2039	2627	2309	1836	1883	1452	1871	1645
22-Aug	2639	2708	2088	2690	2365	1852	1900	1465	1888	1660
23-Aug	2703	2773	2138	2755	2422	1869	1917	1479	1905	1675
24-Aug	2768	2839	2190	2821	2480	1886	1935	1492	1922	1690
25-Aug	2834	2908	2242	2889	2539	1903	1952	1505	1939	1705
26-Aug	2902	2977	2296	2958	2600	1920	1970	1519	1957	1720
27-Aug	2972	3049	2351	3029	2663	1937	1987	1533	1974	1736
28-Aug	3043	3122	2407	3102	2727	1955	2005	1546	1992	1751
29-Aug	3116	3197	2465	3176	2792	1972	2023	1560	2010	1767

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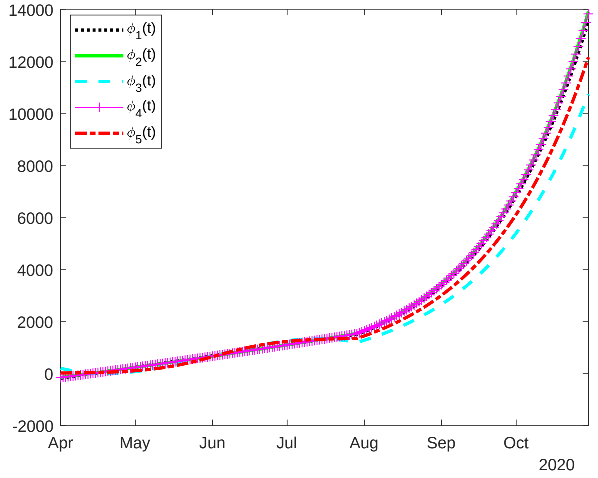
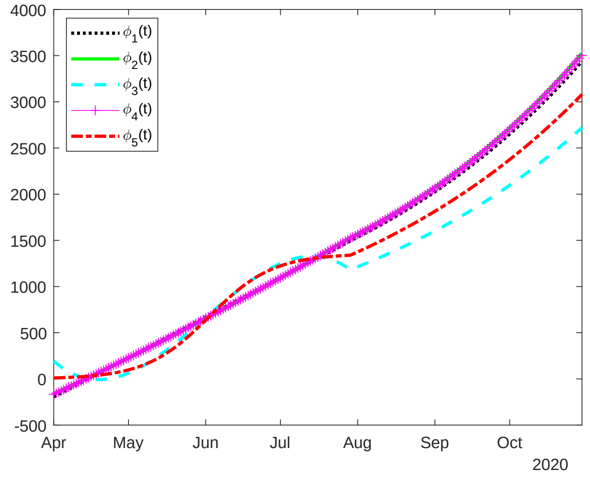
Table 4 – continued from previous page

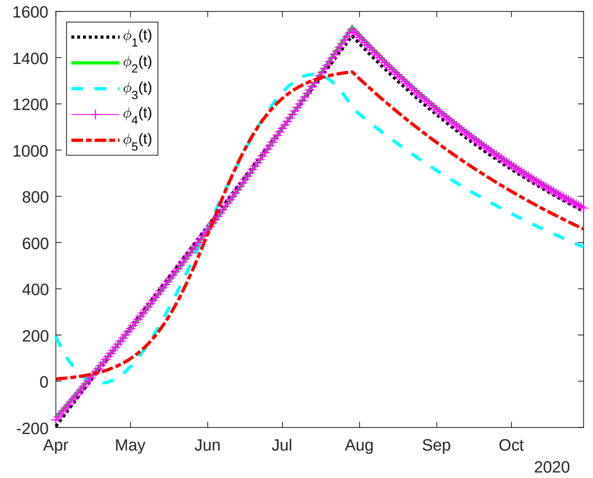
30-Aug	3191	3274	2524	3252	2859	1990	2042	1574	2028	1783
31-Aug	3268	3352	2585	3330	2928	2008	2060	1588	2046	1799
	$R = 0.9924$					$R = 0.9402$				
Day\ ϕ_i	ϕ_1	ϕ_2	ϕ_3	ϕ_4	ϕ_5	ϕ_1	ϕ_2	ϕ_3	ϕ_4	ϕ_5
30-Jul	1483	1521	1173	1511	1328	1405	1441	1111	1432	1258
31-Jul	1471	1509	1164	1500	1318	1321	1355	1045	1346	1183
1-Aug	1460	1498	1155	1488	1308	1242	1274	982	1265	1112
2-Aug	1449	1487	1146	1477	1298	1167	1198	924	1190	1046
3-Aug	1438	1475	1138	1466	1288	1098	1126	868	1119	983
4-Aug	1427	1464	1129	1455	1279	1032	1059	816	1052	925
5-Aug	1416	1453	1120	1443	1269	970	995	768	989	869
6-Aug	1405	1442	1112	1432	1259	912	936	722	930	817
7-Aug	1395	1431	1103	1422	1250	858	880	678	874	768
8-Aug	1384	1420	1095	1411	1240	806	827	638	822	722
9-Aug	1374	1409	1087	1400	1231	758	778	600	773	679
10-Aug	1363	1399	1078	1389	1221	713	731	564	727	639
11-Aug	1353	1388	1070	1379	1212	670	688	530	683	600
12-Aug	1343	1377	1062	1368	1203	630	646	498	642	565
13-Aug	1332	1367	1054	1358	1194	592	608	469	604	531
14-Aug	1322	1357	1046	1348	1185	557	571	441	568	499
15-Aug	1312	1346	1038	1337	1176	524	537	414	534	469
16-Aug	1302	1336	1030	1327	1167	492	505	390	502	441
17-Aug	1292	1326	1022	1317	1158	463	475	366	472	415
18-Aug	1282	1316	1015	1307	1149	435	447	344	444	390
19-Aug	1273	1306	1007	1297	1140	409	420	324	417	367
20-Aug	1263	1296	999	1287	1132	385	395	304	392	345
21-Aug	1253	1286	992	1278	1123	362	371	286	369	324
22-Aug	1244	1276	984	1268	1115	340	349	269	347	305
23-Aug	1234	1266	977	1258	1106	320	328	253	326	286
24-Aug	1225	1257	969	1249	1098	301	308	238	306	269
25-Aug	1216	1247	962	1239	1089	283	290	224	288	253
26-Aug	1207	1238	955	1230	1081	266	273	210	271	238
27-Aug	1197	1228	947	1220	1073	250	256	198	255	224
28-Aug	1188	1219	940	1211	1065	235	241	186	239	210
29-Aug	1179	1210	933	1202	1057	221	227	175	225	198
30-Aug	1170	1201	926	1193	1049	208	213	164	212	186
31-Aug	1161	1192	919	1184	1041	195	200	154	199	175



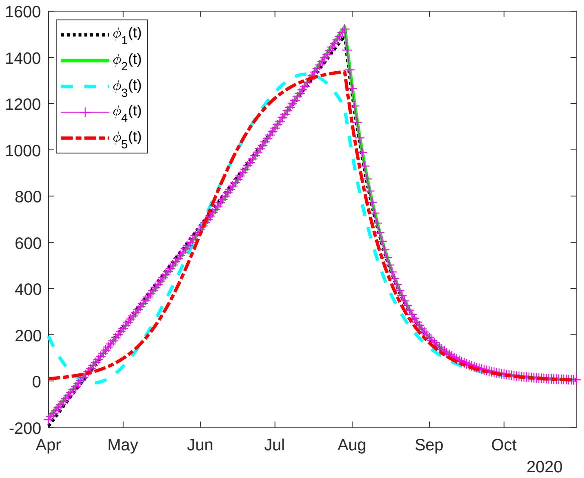
(a) R = 1.024, for 120 days



(b) R = 1.009, for recent 75 days

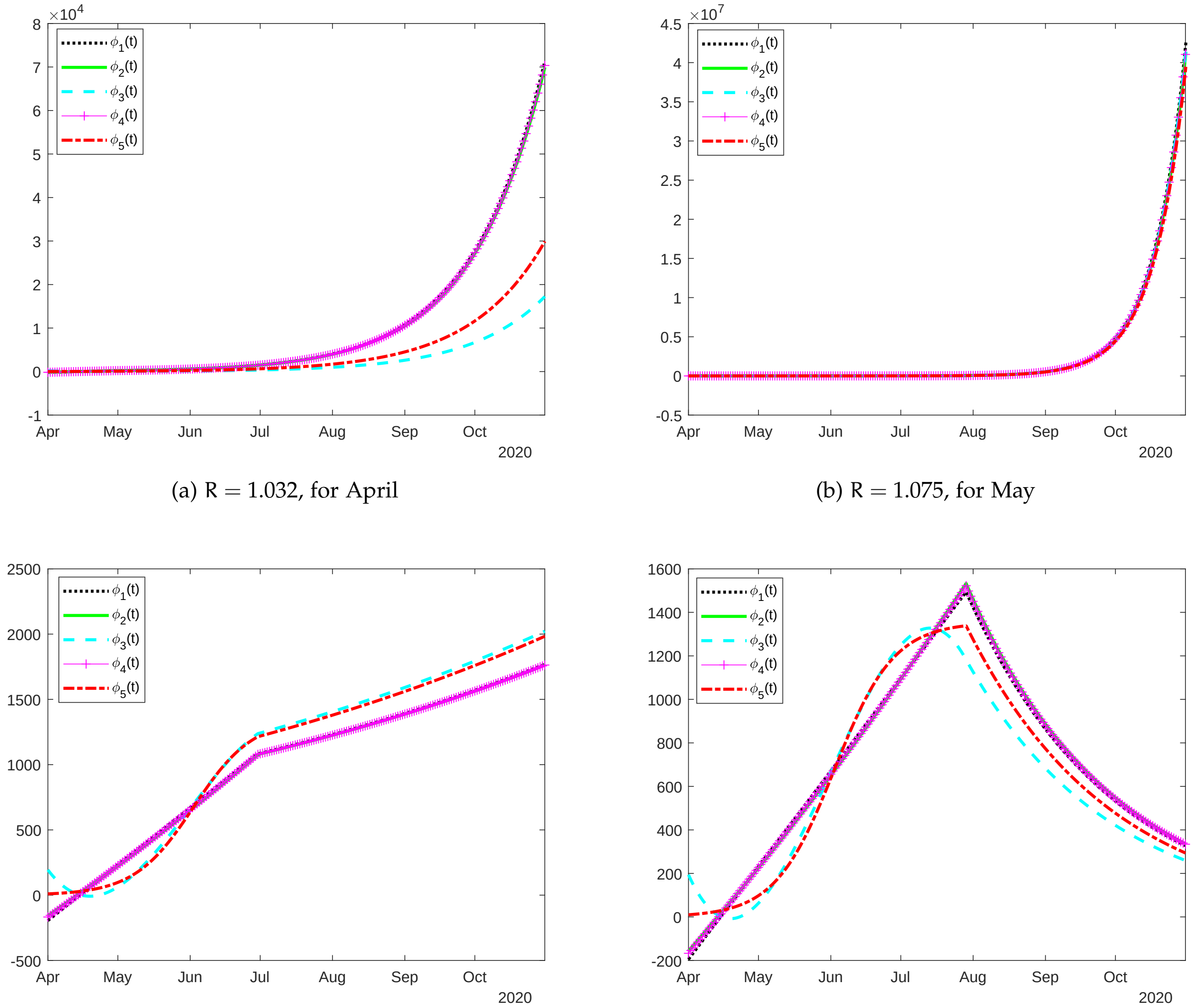


(c) R = 0.9924, for recent 60 days



(d) R = 0.9402, for recent 15 days

Figure 3: Predicted number of infected cases of COVID-19 in Oman from April 1- October 31, 2020.



(a) R = 1.032, for April

(b) R = 1.075, for May

(c) R = 1.004, for June

(d) R = 0.9840, for July

Figure 4: Monthly predicted of infected cases of COVID-19 in Oman from April.

4. Conclusions

A prediction of the spread of the COVID-19 epidemic in Oman is presented using the methods of least-squares data fitting for the period of April 1 to July 29, 2020 and forecasts the future daily infected cases. We also introduced the new ratio measure to modify the models so that estimation of the daily infected cases becomes reasonable.

Finally, it is worth noting that the proposed analysis in predicting the future infected cases can be extended in a similar manner to other cases such as the daily number of death cases (as shown in Fig. 5). Using the period of April 1 to July 29, 2020 recorded death cases of COVID-19 in Oman, we obtain R=0.9920 and as shown in Fig. 5, it is predicted that the number of death cases is steady increasing and reaches the peak of 11 deaths by the end of July.

As for the daily number of recovery cases, since the recovery case is obtained due to successful treatments of the infected case, the recorded recovery cases are usually reported in terms of percentage of the infected case. Therefore, perhaps with a time delay to represent treatments, the predicted infected cases can be used to obtain the number of daily recovery cases.

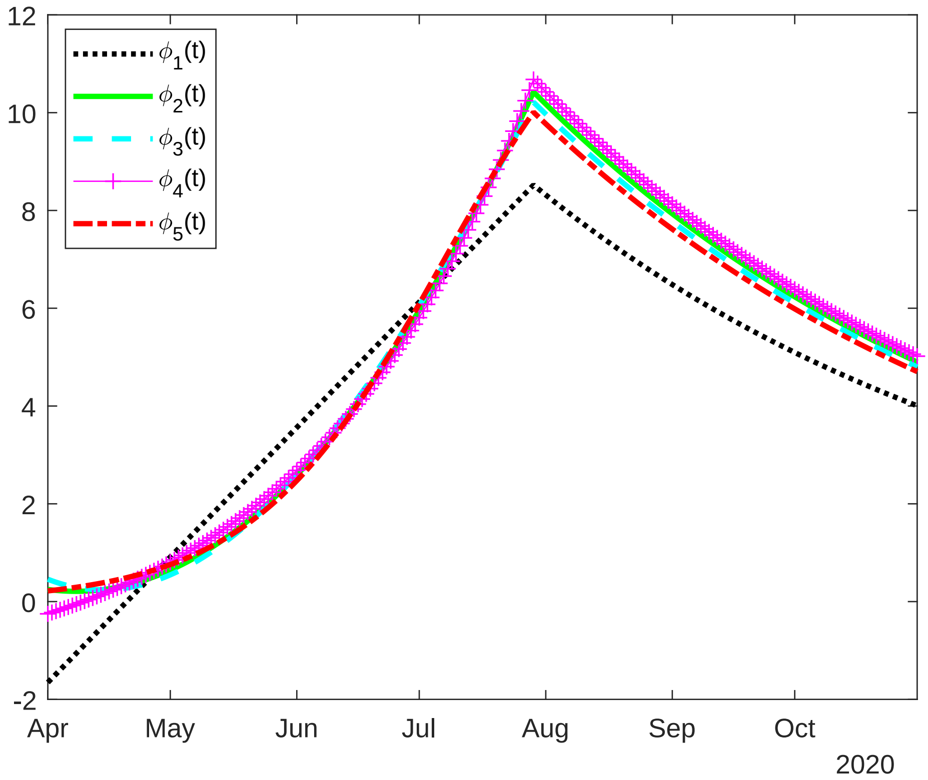


Figure 5: Predicted death cases of COVID-19 in Oman from April 1- October 31, 2020.

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Appendix

In Table 5, we report some data on daily cases of COVID-19 in Oman that are available from the Ministry of Health, Oman through the websites [11] and [14]. The table under the headings Number of New Cases, Number of New Recoveries, Number of New Death and their accumulated cases, where t_i and y_i, for $i \geqslant 1$, denote the order number of day i and the number of infected cases reported in day i, respectively. The footnote Mi, for $i = 1, 2, 3, 4$, denote the first day of the months of April, May, June and July 2020, respectively.

Table 5: Daily reported of infected cases of COVID-19 in Oman for the peroid of April 1– July 29, 2020.

t_i: Time in Days	y_i: Number of New Cases	Number of New Recoveries	Number of New Death		Number of Accumulated Cases	Number of Accumulated Recoveries	Number of Accumulated Death
1[M1]	18	2	1		210	34	1
2	21	7	0		231	41	1
3	21	16	0		252	57	1
4	25	4	1		277	61	2
5	21	0	0		298	61	2
6	33	0	0		331	61	2
7	40	6	0		371	67	2
8	48	5	0		419	72	2
9	38	0	1		457	72	3
10	27	0	0		484	72	3
11	62	37	0		546	109	3
12	53	0	1		599	109	4
13	128	15	0		727	124	4
14	86	6	0		813	130	4
15	97	1	0		910	131	4
16	109	45	0		1019	176	4
17	50	0	2		1069	176	6
18	111	0	0		1180	176	6
19	86	57	0		1266	233	6
20	144	5	1		1410	238	7
21	98	0	1		1508	238	8
22	106	0	0		1614	238	8
23	102	69	1		1716	307	9
24	74	18	1		1790	325	10
25	115	4	0		1905	329	10
26	93	4	0		1998	333	10
27	51	31	0		2049	364	10
28	82	0	0		2131	364	10
29	143	0	0		2274	364	10
30	74	131	1		2348	495	11
31[M2]	99	0	0		2447	495	11
32	36	255	1		2483	750	12
33	85	0	0		2568	750	12
34	69	66	0		2637	816	12
35	98	42	1		2735	858	13

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t_i: Time in Days	y_i: Number of New Cases	Number of New Recoveries	Number of New Death		Number of Accumulated Cases	Number of Accumulated Recoveries	Number of Accumulated Death
36	168	30	0		2903	888	13
37	55	92	2		2958	980	15
38	154	45	1		3112	1025	16
39	112	43	1		3224	1068	17
40	175	49	0		3399	1117	17
41	174	94	0		3573	1211	17
42	148	39	0		3721	1250	17
43	298	39	0		4019	1289	17
44	322	14	1		4341	1303	18
45	284	47	2		4625	1350	20
46	404	86	1		5029	1436	21
47	157	29	1		5186	1465	22
48	193	31	3		5379	1496	25
49	292	78	2		5671	1574	27
50	372	87	3		6043	1661	30
51	327	160	0		6370	1821	30
52	424	0	4		6794	1821	34
53	463	27	2		7257	1848	36
54	513	85	1		7770	1933	37
55	0	0	0		7770	1933	37
56	348	134	0		8118	2067	37
57	255	110	2		8373	2177	39
58	636	0	1		9009	2177	40
59	811	219	1		9820	2396	41
60	603	0	0		10423	2396	41
61	1014	286	8		11437	2687	49
62[M3]	786	0	1		12223	2687	50
63	576	0	9		12799	2687	59
64	738	163	8		13537	2850	67
65	778	606	0		14316	3456	67
66	770	0	5		15086	3456	72
67	930	0	0		16016	3456	72
68	866	0	3		16882	3456	75
69	604	342	6		17486	3798	81
70	712	359	2		18198	4157	83
71	689	1488	1		18887	5645	84
72	1067	983	5		19954	6628	89
73	1117	866	7		21071	7494	96
74	1006	41	3		22077	7535	99
75	1404	924	5		23481	8459	104
76	1043	1074	4		24524	9533	108
77	745	1556	6		25269	11089	114
78	810	708	2		26079	11797	116
79	739	1467	3		26818	13264	119
80	852	710	6		27670	13974	125

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t_i: Time in Days	y_i: Number of New Cases	Number of New Recoveries	Number of New Death		Number of Accumulated Cases	Number of Accumulated Recoveries	Number of Accumulated Death
81	396	806	3		28566	14780	128
82	905	772	3		29471	15552	131
83	1605	856	6		31076	16408	137
84	1318	871	3		32394	17279	140
85	1142	693	2		33536	17972	142
86	1366	548	2		34902	18520	144
87	1132	962	9		36034	19482	153
88	919	881	6		36953	20363	159
89	1197	837	4		38150	21200	163
90	910	1222	6		39060	22422	169
91	1010	1003	7		40070	23425	176
92^{M4}	1124	737	9		41194	24162	185
93	1361	1156	3		42555	25318	188
94	1374	851	5		43929	26169	193
95	1177	799	10		45106	26968	203
96	1072	949	10		46178	27917	213
97	1557	1229	5		47735	29146	218
98	1262	1854	6		48997	31000	224
99	1210	1005	9		50207	32005	233
100	1518	1016	3		51725	33021	236
101	1889	1204	8		53614	34225	244
102	1083	1030	4		54697	35255	248
103	1318	843	9		56015	36098	257
104	2164	1159	2		58179	37257	259
105	1389	730	14		59568	37987	273
106	1679	1051	8		61247	39038	281
107	1327	1052	9		62574	40090	290
108	1619	1360	8		64193	41450	298
109	1311	1322	10		65505	42772	308
110	1157	1232	10		66661	44004	318
111	1793	1146	8		68400	45150	326
112	1487	1458	11		69887	46608	337
113	1660	1314	12		71547	47922	349
114	1099	3427	6		72646	51349	355
115	1145	1658	4		73791	53007	359
116	1067	1054	12		74858	54061	371
117	1147	1238	13		76005	55299	384
118	1053	1729	9		77058	57028	393
119	846	1559	9		77904	58587	402
120	665	1653	10		78569	60240	412

^{M1}: April, ^{M2}: May, ^{M3}: June, ^{M4}: July.