



[J Public Hlth Dev] Editor Decision

1 pesan

Cheerawit Rattanapan via Thai Journals Online (ThaiJO) <admin@tci-thaijo.org>

25 Februari 2023 pukul 10.19

Balas Ke: Cheerawit Rattanapan <cheerawit.rat@mahidol.edu>

Kepada: Yasser Abd Djawad <yasser.djawad@unm.ac.id>, Ridwansyah <ridwansyah@unm.ac.id>, Hendra Jaya <hendra.jaya@unm.ac.id>, Sutarsi Suhaeb <sutarsi.suhaeb@unm.ac.id>, Suhartono <suhartono@unm.ac.id>

Yasser Abd Djawad, Ridwansyah, Hendra Jaya, Sutarsi Suhaeb, Suhartono:

We have reached a decision regarding your submission to Journal of Public Health and Development, "A system model for real-time monitoring and geospatial analysis of COVID-19 spread".

Our decision is to: Resubmit for Review

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[J Public Hlth Dev] Editor Decision

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Cheerawit Rattanapan via Thai Journals Online (ThaiJO) <admin@tci-thaijo.org>

22 Maret 2023 pukul 21.35

Balas Ke: Cheerawit Rattanapan <cheerawit.rat@mahidol.edu>

Kepada: Yasser Abd Djawad <yasser.djawad@unm.ac.id>, Ridwansyah <ridwansyah@unm.ac.id>, Hendra Jaya <hendra.jaya@unm.ac.id>, Sutarsi Suhaeb <sutarsi.suhaeb@unm.ac.id>, Suhartono <suhartono@unm.ac.id>

Yasser Abd Djawad, Ridwansyah, Hendra Jaya, Sutarsi Suhaeb, Suhartono:

We have reached a decision regarding your submission to Journal of Public Health and Development, "A system model for real-time monitoring and geospatial analysis of COVID-19 spread".

Our decision is: Revisions Required

Dear Author

Please note that all revised manuscripts will be evaluated for changes made. Please use red font or highlights to indicate the revised portions of your manuscript. The revised manuscript should also be accompanied by a summary of your responses to the reviewers' comments, item by item.

Please resubmit your revised manuscript by March 31, 2023.

Best regards,

Editor

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[J Public Hlth Dev] Editor Decision

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Cheerawit Rattanapan via Thai Journals Online (ThaiJO) <admin@tci-thaijo.org>

27 Maret 2023 pukul 21.07

Balas Ke: Cheerawit Rattanapan <cheerawit.rat@mahidol.edu>

Kepada: Yasser Abd Djawad <yasser.djawad@unm.ac.id>, Ridwansyah <ridwansyah@unm.ac.id>, Hendra Jaya <hendra.jaya@unm.ac.id>, Sutarsi Suhaeb <sutarsi.suhaeb@unm.ac.id>, Suhartono <suhartono@unm.ac.id>

Yasser Abd Djawad, Ridwansyah, Hendra Jaya, Sutarsi Suhaeb, Suhartono:

We have reached a decision regarding your submission to Journal of Public Health and Development, "A system model for real-time monitoring and geospatial analysis of COVID-19 spread".

Our decision is to: Accept Submission

Your manuscript will be published on Volume 21 No. 2 (May-August) 2023

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A system model for Real-time Monitoring and Geospatial Data for the Simulation of COVID-19 surveillance in Sulawesi, Indonesia

Yasser Abd Djawad^{1*}, Ridwansyah¹, Hendra Jaya¹ Sutarsi Suhaeb¹, Suhartono²

¹Electronics Engineering Department, Engineering Faculty, Universitas Negeri Makassar, Indonesia

² Computer Engineering Department, Engineering Faculty, Universitas Negeri Makassar, Indonesia

*Corresponding author. Tel.: +62-813-41735386; Email address: yasser.djawad@unm.ac.id

Abstract

The rapid spread of COVID-19 required rapid management. Prompt treatment was needed to prevent the spread of this disease, which could be minimized or isolated in one place so that it did not spread to other places. This study was conducted to discover a model of the surveillance system in real time and to analyze the change of its distribution pattern. This study was conducted in the city of Makassar, South Sulawesi, Indonesia, involving 30 volunteers. Two devices were used, the Internet reverse transcription loop-mediated isothermal amplification (iRTLAMP) and IoT button application, to provide spatial data in the form of patient points exposed to COVID-19. Furthermore, three scenarios were applied to see the pattern of data distribution. The data recorded in the cloud database were retrieved with an application created and then analyzed using Point Pattern Analysis (PPA) to observe the distribution of patterns in real time. The analysis utilizing Kernel Density Estimation (KDE) with the Gaussian kernel function as the kernel revealed significant changes in the probability distribution, which could be seen from color changes in the map. The centographic analysis revealed that the mean and median points of the three scenarios changed in various ways within approximately 700 m to 1.7 km. Meanwhile, the radius of minimal bounding circle behaved similarly and appeared to change from radius 5.57 km to 6.55 km and 6.22 km. The standard distance also showed a

change from 4.53 km to 4.60 km, 4.70 km and 5.40 km. Simulations carried out using the developed system showed that the use of internet devices could help monitor people exposed to COVID-19 by changing patterns and distribution points. Therefore, decision makers could take preventive actions earlier so that this disease did not spread quickly.

Keywords: Point pattern analysis, COVID-19, Sulawesi, Indonesia.

1. Introduction

Covid-9 is still spreading quickly in some countries, including Indonesia. The current situation remains unstable, with the emergence of several new variants that spread more quickly and cause different symptoms in different patients.¹⁻⁴ Currently the spread of COVID-19 can be through droplets,⁵ aerosols,⁶ and fomites.⁷ In addition, the spread of COVID-19 is also affected by the weather,⁸ temperature, humidity and population density.⁹ In Indonesia, several policies were implemented by the central and local governments to prevent rapid spread, such as limiting the number of people entering public places and limiting the movement of people between regions, districts, and cities, as well as between islands.¹⁰ However, this restriction affects many sectors, including the economy, which has a major impact on people's incomes.¹¹ For this reason, to prevent a more massive spread of the COVID-19 virus, a **real time analysis of the spread pattern of COVID-19 is necessarily required.**

In order to prevent the spread of COVID-19, cooperation with various fields other than health sciences such as information technology and geography should be done.¹² Information systems and technology are needed to provide fast access to various types of information, such as the number and location of deployment. Several systems and information technology have been developed in Indonesia, and the updating process is conducted once a day.¹³⁻¹⁵ This information is provided by relevant authorities in order to maintain the validity of the data provided. The drawback of this method is that the spread cannot be monitored in real time,

resulting in a weak anticipation of the spread of the virus. Meanwhile, the use of geography approach is required to map and analyze the spread pattern of COVID-19 within some areas by including other factors such as the characteristics of the area, the weather, population distribution and density, etc. The combination of these various fields of knowledge is expected to make a significant contribution to preventing the spread of COVID-19. The use of spatial analysis in solving problems has been carried out by many researchers.^{16,17} GIS has also been widely employed for mapping and monitoring the distribution of diseases, including COVID-19.^{18,19}

In general, in cases of the spread of COVID-19, GIS is used to map the number and location of the spread. GIS could be used as a tool to monitor and track the spread of COVID-19. To get real-time data as spatial data in GIS, several techniques have been used, such as using mobile phone,²⁰ sensor web service,²¹ and data warehouse combined with Application Programming Interface (API).²² Several methods have been used to analyze the spread of COVID-19 geospatially.²³⁻²⁵ In this study, we used the data collected by IoT devices because it is easy to use and reliable²⁶ and analyzed the patterns of data distribution by using Point Pattern Analysis (PPA) to provide better visualization and interpretation of the data distributed by points.^{27,27,28}

2. Methods

2.1 Study Area

The study conducted in the city of Makassar, located at longitude 119.423790 and latitude -5.135399. Makassar is located on the island of Sulawesi, Indonesia, and that corresponds to the Köppen climate classification category Am. Based on the population census in 2020, the total population was around 1,423,877 with a population density of 8,101/km² inhabiting 15 sub-districts.²⁹

2.2 System design

A point collected in the location of each COVID-19 case offered two values, the position of the point itself and the value that exists at that point. The points in the form of spatial data spread over certain locations on a map and were called point patterns. The analysis conducted using the position of the points spread over several locations on the map with the value. In the case of the spread of COVID-19, the analysis was conducted using the position of the points spread over several locations on the map with the value of the point themselves. In this study, the positions of the points on the map obtained from two devices, namely the internet reverse transcription loop mediated isothermal amplification (iRTLAMP) and the IoT button application on Android device as shown in Figure 1. iRTLAMP is an RT-LAMP³⁰ device for COVID-19 testing equipped with Internet of Things (IoT) features on the device so that it can transmit the position of the device. This device was placed at a hospital and used to detect whether a person exposed to COVID-19 by using the saliva sample from the person who wanted to be tested. If the device detected COVID-19, the IoT module sent the longitude and latitude of the hospital to the cloud database (Firebase) to record the position of the exposed person. The IoT Button was an Android-based IoT application that sent the location to the Firebase if the user was exposed to COVID-19 using other test methods, such as Polymer Chain Reaction (PCR) and antigen. The main function of this application was to send input data in the form of an identification number (*NIK, Nomor Induk Kependudukan*), which is the detailed information about the patient previously entered during registration. Both platform devices collected the data for each COVID-19 infected case in the form of longitude and latitude on the map. The IoT button application should also be available in public health centers (PHC) and hospitals that carry out PCR tests or other offline COVID tests. If someone was detected with COVID using the offline method, staff from the PHC or hospital could enter patient data through the IoT button application. Both platform devices collected the data for

each COVID-19 infected case in the form of longitude and latitude on the map.

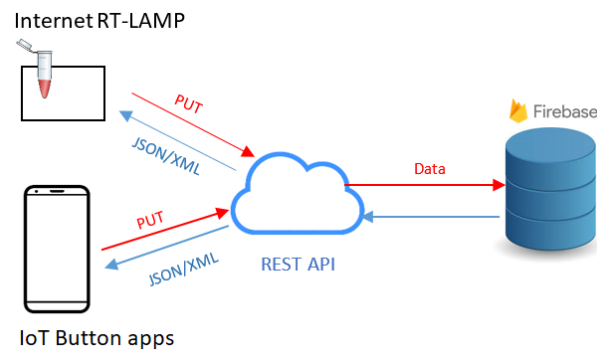


Figure 1 Storing real-time data using Iot Button apps and iRTLAMP

The next step was to retrieve data by using Python 3.9.12³¹ to export data in a CSV format. Then, the data were analyzed by using Python 3.9.12 on the same computer with the data on CSV file and update spatial data in the form of points on a predetermined map which was then analyzed using PPA³² as shown in Figure 2. In general, the program was divided into three categories: delivery, data retrieval, and analysis.

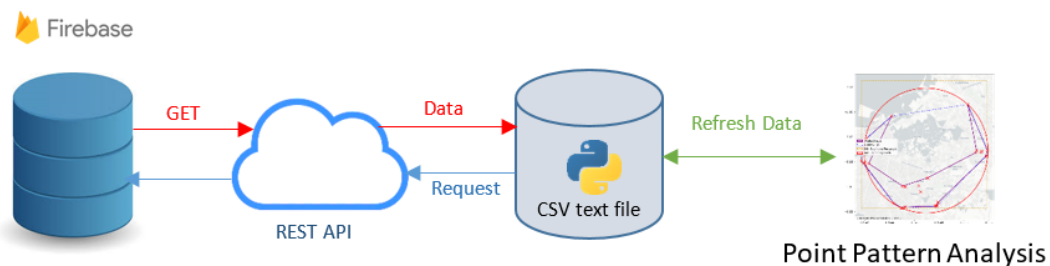


Figure 2 Obtaining real-time data form Firebase and analysis using Point Pattern Analysis

2.3 Data generation

To analyze the distribution patterns of the points, a simulation was conducted with three scenarios:

1. Scenario 1: five points were added at the edge of an existing cluster.

2. Scenario 2: five were added at the center of an existing cluster.
3. Scenario 3: five were added as a new cluster.

This simulation was conducted in the city of Makassar, South Sulawesi, Indonesia, involving volunteers using iRTLAMP devices and the IoT button application. Volunteers who participated in this study were not exposed to COVID-19 and only used the device and application as a simulation of the system. Thirty points were generated and no existing data were used because the priority was to determine whether the delivery and analysis process in real time could function properly.

2.4 Data Analysis

Point pattern analysis was performed to observe changes in point patterns by examining the distribution of points on the map. Changes in the distribution of points on the map also caused changes in their patterns. By examining the pattern of changes from these points, it was expected that the nature of pattern changes resulting from changes in the distribution of points will be understood. In addition, by examining the existing patterns, it was expected that the spread of COVID-19 can be predicted so that prevention could be carried out in locations that may become new clusters for the spread of this disease. To determine the distribution of data, the first step was to plot the location of people exposed to COVID-19 on a map to determine the distribution of people exposed to COVID-19 in the form of points. To analyze the density of these points and classify the points in the cluster, this study performed several analyses, namely Kernel Density Estimation (KDE) analysis and centrography. KDE is a method used to estimate the probability of a density function from data. The kernel used in this study is a Gaussian Kernel expressed as follows:

$$KDE_j = \frac{1}{n} \sum_{i=1}^n \frac{1}{h\sqrt{2\pi}} e^{-0.5 \frac{(x_j - x_i)^2}{h^2}} \quad (1)$$

where n is the number of observed data points, h is the bandwidth, x_i are observed data points, and x_j are series of data point where kernel function is calculated.

The next step was centrographic analysis. Centographic analysis is an analytical technique that provides summary of the point pattern such as center point, dispersion and shape of the pattern. Given these mean and median points, it is also possible to calculate the distance from the center location when there is a new distribution. The purpose of this analysis was to identify the center of spread. The mean and median centers are computed as follows:

$$x_{mc} = \frac{1}{n} \sum_{i=1}^n x_i \quad (2)$$

$$y_{mc} = \frac{1}{n} \sum_{i=1}^n y_i \quad (3)$$

while the Euclidean median can be expressed as:

$$\min f(x_{em}, y_{em}) = \sum_{i=1}^n \sqrt{(x_i - x_{em})^2 + (y_i - y_{em})^2} \quad (4)$$

In order to measure standard distance (SD) for dispersion analysis, this standard deviation formula was used:

$$SD = \sqrt{\frac{\sum_{i=1}^n (x_i - x_{mc})^2}{n} + \frac{\sum_{i=1}^n (y_i - y_{mc})^2}{n}} \quad (5)$$

Meanwhile, to calculate the distance between two locations with known longitude and latitude, the following haversine formula was used as follows:

$$h = \sin^2(\Delta\phi/2) + \cos\phi_1 \cdot \cos\phi_2 \cdot \sin^2(\Delta\lambda/s) \quad (6)$$

$$c = 2 \cdot \text{atan}^{-1}(\sqrt{h}, \sqrt{1-h})$$

$$d = R \cdot c$$

where λ is longitude and ϕ is latitude and R is equal to 6378 km (earth's radius).

Furthermore, the minimum bounding rectangle was drawn based on the smallest rectangle that can be formed from the existing points. In other words, a minimum bounding rectangle was

drawn using the outermost existing points. Meanwhile, the minimum bounding circle was drawn using the Skyum algorithm.³³

3. Results

To determine the distribution of the data, the first step was to plot the location of people exposed in the form of points. The initial point distribution was 30 points, as shown in Figure 3a, and three scenarios were used, as shown in Figures 3b, 3c, and 3d, where changes in spatial data were seen in the form of adding points that followed the three scenarios carried out in this study, which are indicated by the red circles. It can be seen from the figure that the points are scattered randomly on the map, showing the distribution locations of people who have been exposed to COVID-19. However, this visualization does not provide sufficient information to clearly show the distribution pattern because it only describes randomly scattered points.

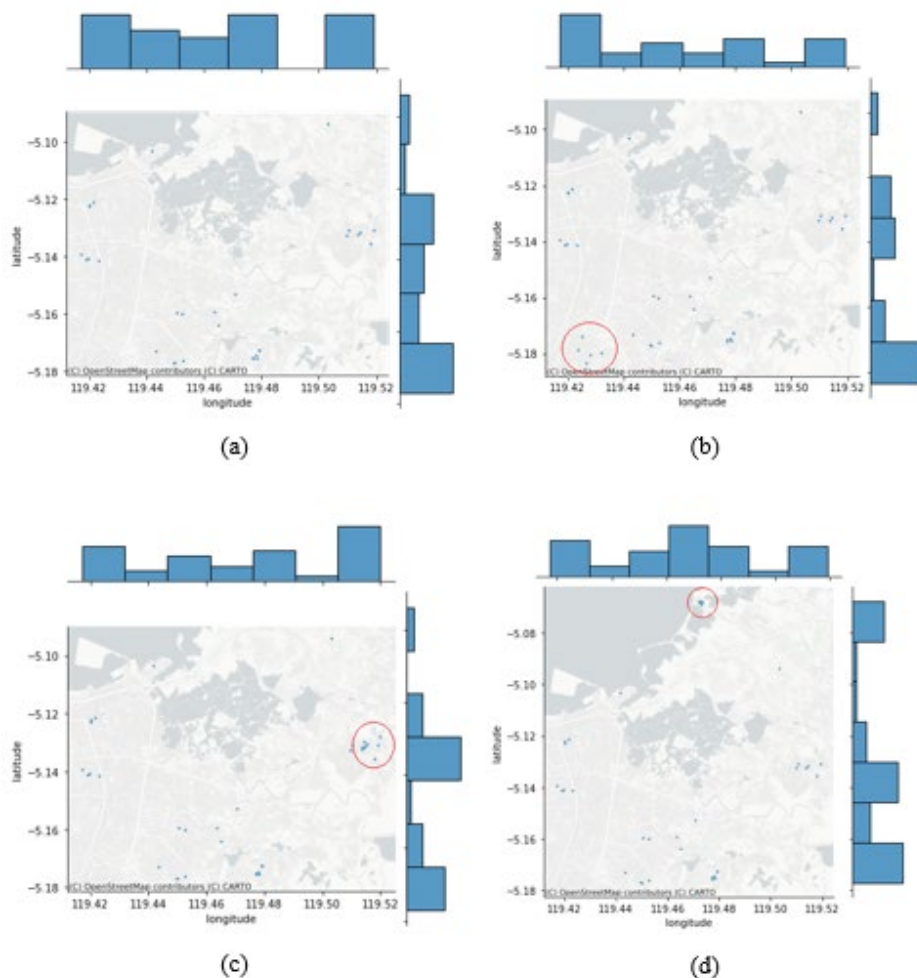


Figure 3 The distribution of exposed to COVID-19 spread on the map in the form of points and changes in spatial data in the form of points by following the third scenario. Changes in spatial data can be seen in the red circle

Furthermore, KDE analysis was performed to determine the density difference in the cluster areas of the three clusters formed. In addition, the density indicated by the darker color in the center of each cluster also shows a difference. Figure 4b shows the addition of points using Scenario 1, where it can be seen that the cluster at the bottom of the map will widen, which is the impact of adding points to the cluster compared to Figure 4a, which is the initial point distribution. With the addition of a number of points in other clusters using Scenario 2, it can be seen that the density in that cluster changes, which is indicated by a darker color in the center of the cluster, as shown in Figure 4c. Meanwhile, adding points at other locations on the map creates a new cluster, namely the 4th cluster as shown in Figure 4d.

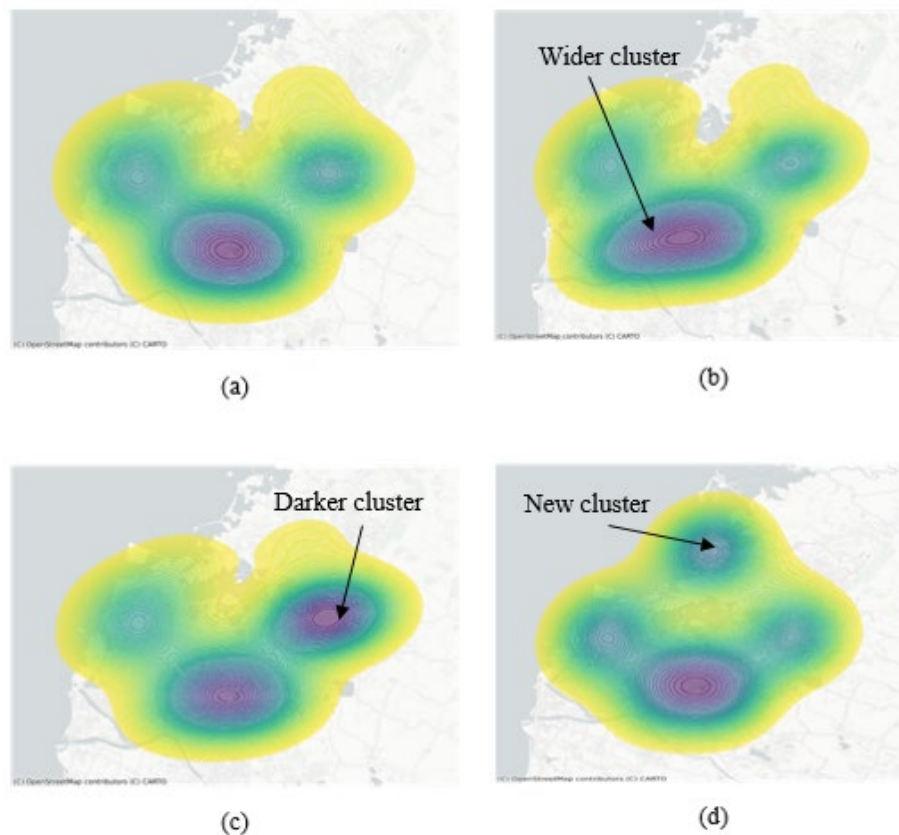


Figure 4 Changes that occur in the cluster using KDE analysis in the three scenarios; (a) initial (b) scenario 1 (c) scenario 2 (d) scenario 3.

The results of the centography are obtained by calculating the mean and median of the distribution of points, SD and calculating the minimum bounding rectangle and minimum bounding circle. From Figure 5, it can be observed that there was a shift in the mean center (black x) and median center (black dot) to the new mean (red x) and new median (red dot) when applied to the three scenarios. The mean point represents the average value of the point pattern in the distribution, and the median point represents the middle value of the existing point pattern. Changes in the median and mean points, as well as the distance from the median and mean starting points, based on the three scenarios are shown in Tables 1 and 2.

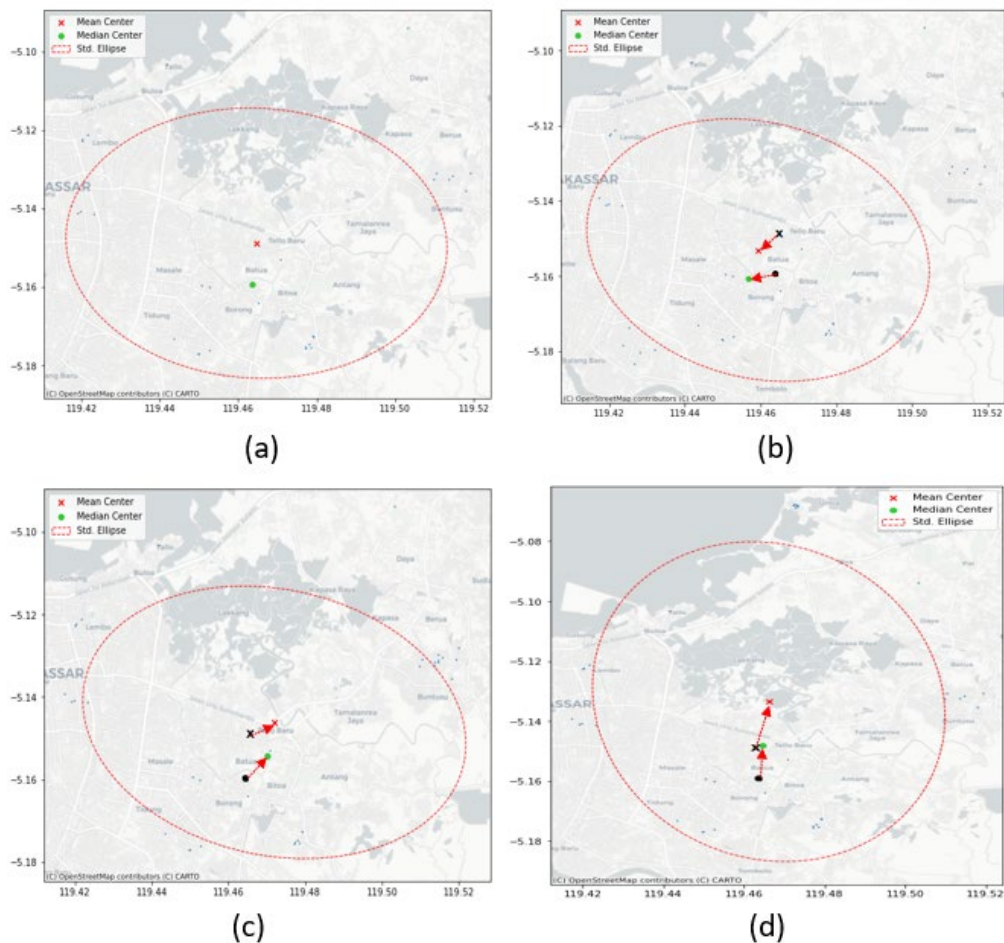


Figure 5 The initial mean center (black x) and initial median center (black dot) changes that occurred to the new mean (red x) and new median (green dot) in the clusters using centographic analysis in the three scenarios; (a) initial (b) Scenario 1 (c) Scenario 2 (d) Scenario 3.

Table 1 Longitude and latitude of mean including distance from initial point changes during simulation with three scenarios

	Location		Distance (km)
	Longitude	Latitude	
Center	119.46463257	-5.14878677	0
Scenario 1	119.45926683	-5.15312129	0.76
Scenario 2	119.47192769	-5.14612440	0.86
Scenario 3	119.46618497	-5.13351557	1.70

Table 2 Longitude and latitude of median including distance from initial point changes during simulation with three scenarios

	Location		Distance (km)
	Longitude	Latitude	
Center	119.46362200	-5.15918400	0
Scenario 1	119.45676376	-5.16075840	0.78
Scenario 2	119.47017913	-5.15436299	0.90
Scenario 3	119.46472863	-5.14818226	1.23

Furthermore, by using the visual form of the spatial distribution, several types of boundary shapes were used, namely, minimum bounding rectangles, which were made in the form of a boundary in the form of a square that was the minimum square shape or the smallest square area that could be made in the existing spatial distribution. Next, we searched for the minimum bounding circle that described the minimum circle shape with a minimum area that could limit the spatial distribution. In principle, it is almost the same as minimum bounding rectangles with only a limiting shape. The convex hull shape is a line that connects the outermost points of the spatial distribution and never forms a closed pattern within the shape itself. Another shape is the alpha shape, which is a stricter version of the convex hull. It is a line that connects all the outermost points of the spatial pattern and can go back inside itself to form a tighter pattern than the convex hull. The visual form of this barrier is shown in Figure 6. The pattern of this barrier also seems to change according to the pattern of the three scenarios that have been carried out. **Table 3 shows the mean and median of the distribution of points, SD, and**

radius of minimum bounding circle changes for three scenarios. The standard distance in the three scenarios also seemed to change indicating that these points were moving away from the mean center. This also explains why the larger the SD, the farther the points were spread from the mean center. The midpoint and radius of the minimum bounding circle also seemed to change in scenarios 1 (6.559 Km) and scenario 3 (6.225 Km) due to the addition of points on the outermost. While in scenario 2, there was no change in the minimum bounding circle because the additional points were in the circle.

Table 3. Middle point, standard distance (SD) and radius minimum bounding circle (MBC) changes during simulation using three scenarios.

Scenario	Longitude	Latitude	SD (km)	radius (km)
Initial	119.469577764322787	-5.1309623877841855	4.53	5.57
Scenario 1	119.464918	-5.138469	4.60	6.55
Scenario 2	119.469577764322787	-5.1309623877841855	4.70	5.57
Scenario 3	119.4638295294032	-5.122856959886026	5.40	6.22

The results of calculating the minimum rectangular boundary show that there was also a shift in the longitudes and latitudes, which resulted in a change in the size of the rectangle on the map in the three scenarios, as shown in Table 4.

Table 4. Minimum bounding rectangle (MBR) changes during simulation using three scenarios.

Scenario	Left bottom outer most		Right top outer most	
	longitude	latitude	longitude	latitude
Initial	119.417208	-5.177027	119.5191	-5.093878
Scenario 1	119.417208	-5.18342	119.5191	-5.093878
Scenario 2	119.417208	-5.177027	119.5200	-5.093878
Scenario 3	119.417208	-5.177027	119.5191	-5.067597

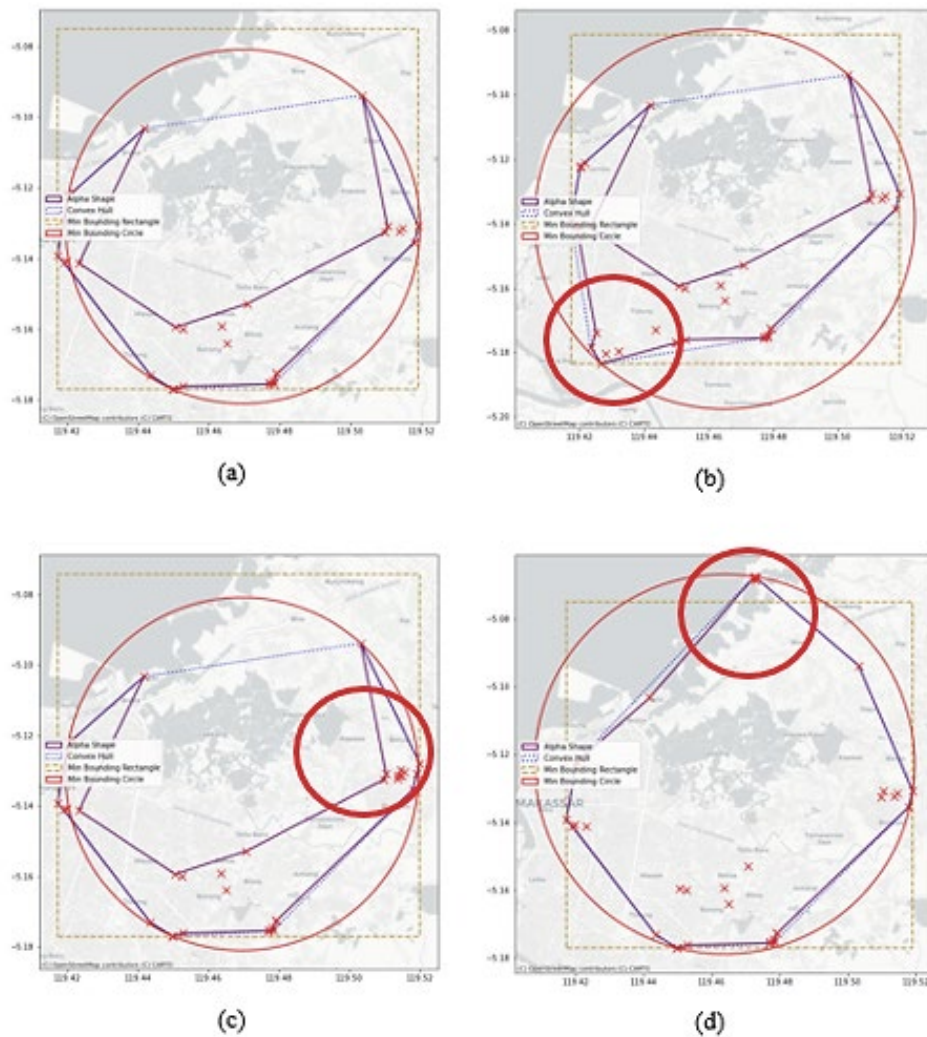


Figure 6 Extent changes during simulation with three scenarios; (a) initial (radius=5.57 Km) (b) scenario 1 (radius=6.55 Km) (c) scenario 2 (radius=5.57 Km) (d) scenario 3 (radius=6.22 Km).

4. Discussion

Simulations carried out using the developed system showed that the use of IoT devices can help monitor people exposed to COVID-19. GIS can be used to analyze, map and visualize the spread of disease.^{27,34} Analysis carried out with PPA can also show changes in the center and patterns of spread when there is an increase in the number of people exposed to an area. This surveillance was intended to minimize the spread by taking prompt and appropriate actions,

such as isolating the place of spread and providing health assistance in areas where the number of people exposed is quite large. Other methods have also been used by researchers, such as the use of a regression model to observe the spread of COVID-19 by conducting cluster analysis in densely populated areas.³⁵ The results showed a correlation between dispersion and a dense population. In addition, mapping and spatial pattern analysis using offline data to analyze the spread pattern of COVID-19 have prevented the spread of COVID-19. The results showed that in dense areas, the spread of COVID-19 was very fast.^{36,37} However, the research that we conducted provides visual information on the situation in the location in real time because it involved the health workers and community so that analysis and prevention can be carried out by decision makers quickly to prevent transmission to other locations promptly.

Some of the problems that may be encountered later in the proposed method are the high price of Internet connections for some people and the low ability of the public in using the applications created. The intensive and structured socialization of related parties and the community of this system requires further studies on the socialization of this system are needed so that this system can be implemented properly and widely. In addition, support from policymakers at the city, provincial, and central levels is needed to encourage all circles to receive this system

5. Conclusions

To determine the spread of the COVID-19 at a location, a real-time system that provides continuous information is needed. This has been solved by a system created using a COVID-19 detection device (iRTLAMP) and a mobile phone application (IoT button) connected in real-time to a map for monitoring and analysis purposes. Analysis using PPA showed that the pattern and extent of spread could be predicted at the location of the spread of COVID-19. Identification of the center of spread and analysis of the spread pattern of the disease, including

COVID-19, are very important to prevent the spread of COVID-19. By knowing the center and the spread pattern, actions such as isolating the place of spread can be taken quickly. The sooner this information is obtained, the sooner the action can be performed. The analysis of the shift in the distribution center provides assistance to related parties to take preventive actions so that new clusters do not appear. The simulation of the monitoring system, central analysis, and distribution pattern in this study show that a real-time data delivery system and PPA could provide accurate information. With this system, it was expected that policymakers at local and national levels would obtain faster and more accurate information about the phenomenon of the spread of diseases such as COVID-19.

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A system model for real-time monitoring and geospatial analysis of COVID-19 spread

Abstract

The rapid spread of COVID-19 requires rapid management. Prompt treatment is needed to prevent the spread of this disease, which can be minimized or isolated in one place so that it does not spread to other places. Identification of the distribution center and how the deployment process is carried out are urgently needed. This study was conducted to discover a model of the surveillance system in real time and analyze the distribution pattern using point pattern analysis (PPA). This study used two devices, namely, the Internet reverse transcription loop-mediated isothermal amplification (iRTLAMP) and the IoT button application, to provide spatial data in the form of patient points exposed to COVID-19. This research was conducted using volunteers deployed in the city of Makassar, Indonesia, to send spatial data in the form of these location points using Internet of Things (IoT) technology to a cloud database that has been created. Furthermore, three scenarios were used to see the pattern of data distribution in the spatial distribution pattern for the process of analyzing the distribution pattern. The data recorded in the cloud database are retrieved by an application created and then analyzed with PPA to analyze the distribution of patterns in real time. From the results, it was found that this system model worked well, and there was also a significant change in the distribution pattern using Kernel Density Estimation (KDE) and centrography techniques.

Keywords  Real-time monitoring, Health geography, Geographical epidemiology, Geographical information system

1. Introduction

The spread of COVID-19 continues in some countries, including Indonesia. The current situation remains unstable, with the emergence of several new variants that spread more quickly and have different symptoms in different patients  Currently the spread of COVID-19

can be through droplets,¹ aerosols,² and fomites.³ In addition, the spread of COVID-19 is also affected by the weather,⁴ temperature, humidity and population density.⁵ In Indonesia, several policies have been implemented by the central and local governments to prevent fleet spread, such as limiting the number of people entering public places and limiting the movement of people between regions, districts, and cities, as well as between islands.⁶ However, this restriction affects many sectors, including the economy, which has a major impact on people's incomes.⁷ For this reason, to prevent a more massive spread of the COVID-19 virus, a method or system that can monitor developments including real-time analysis of the spread of this virus is needed.

In order to prevent the spread of COVID-19, which is spreading rapidly, currently requires cooperation from various fields other than health sciences such as information technology and geography.⁸ Information systems and technology are needed to provide fast access to various types of required information, such as the number and location of deployment. Several systems and information technology have been developed in Indonesia, and the updating process is conducted once a day. This information is provided through the relevant authorities in order to maintain the validity of the data provided.⁹⁻¹¹ The drawback of this method is that the spread cannot be monitored in real time, resulting in a weak anticipation of the spread of the virus. Meanwhile, the use of geography is needed to map and analyze the spread of this virus within some areas by looking at the characteristics of the area such as the weather as well as the distribution and population density. The combination of these various fields of knowledge is expected to make a meaningful contribution to preventing the spread of COVID-19. The use of GIS using spatial analysis in solving problems has been carried out by many researchers.^{12,13} The use of GIS in the field of mapping and monitoring the distribution of diseases, including COVID-19, has also been widely implemented.

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~~Geographic Information System (GIS).~~ In general, in cases of the spread of COVID-19, GIS is used to map the number and location of the spread. GIS makes it easy to monitor and track the spread of COVID virus. To get real-time data as spatial data in GIS, several techniques have been used, such as using mobile phone,¹⁵ sensor web service,¹⁶ and data warehouse combined with Application Programming Interface (API).¹⁷ Several methods are used to analyze the spread of COVID-19 geospatially.¹⁸⁻²⁰ However, in this research IoT technique was used because it is easy to use and reliable²¹ and Point Pattern Analysis (PPA) was used because it provides an effective way for analyzing, visualize and interpret the data distributed by point.^{22,23}

2. Methods

2.1 Study Area

The study was conducted in the city of Makassar, which is located at longitude 119.423790 and latitude -5.135399. Makassar is located on the island of Sulawesi, Indonesia, and has a tropical monsoon climate. Based on the population census in 2020, the total population is around 1,423,877 and a population density of 228,237 people/km² inhabiting 15 sub-districts.²⁴

2.2 System design

A point in the form of spatial data can be seen as two views, namely the position of the point itself and the value that exists at that point. The point spread over certain locations on a map are called point patterns (~~point patterns~~). In the case of the spread of COVID-19, the analysis was conducted using the position of the points spread over several locations on the map with the value of ~~the point itself~~. In this study, the positions of the poin on the map were obtained through 2 devices, namely the internet reverse transcription loop mediated isothermal amplification (iRTLAMP) and the IoT button application shown in Figure 1. iRTLAMP is an RT-LAMP²⁵ device that has been added with Internet of Things (IoT) features on the device

so that it can transmit the position of the device. This device was placed at a hospital and used to detect whether a person had been exposed to COVID-19 by taking a saliva sample from the person who wanted to be tested. If the device detects COVID-19, the IoT module sends the longitude and latitude of the hospital to the cloud database (Firebase) to record the position of the exposed person. Likewise, the IoT Button is an Android-based IoT application that sends the location to the Firebase of the user if the user has been exposed to COVID-19 using other test methods, such as Polymer Chain Reaction (PCR) and antigen. In addition, the main function of this application is to send input data in the form of an identification number (N~~o~~), which is the name of the village that was previously entered during registration. Data in the form of longitude and latitude from these two devices are points on the map to be analyzed.

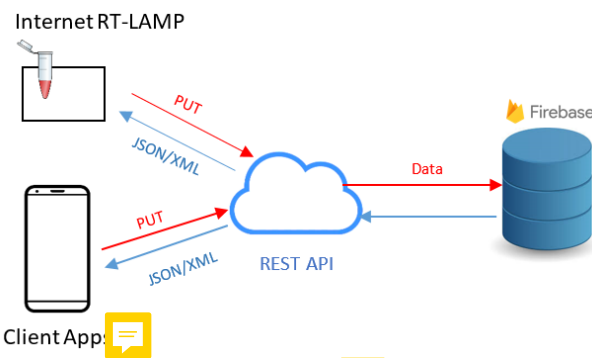


Figure 1 Store real-time data using Android Apps and iRTLAMP

The next step is to create a continuous data retrieval program using the Python programming language and record the results in a CSV format file. The analysis application is also made using Python on the same computer with the data on CSV file and update spatial data in the form of points on a predetermined map which is then analyzed using ~~Point Pattern Analysis~~ (PPA)²⁶ as shown in Figure 2. In general, a program is divided into three categories: delivery, data retrieval, and analysis.

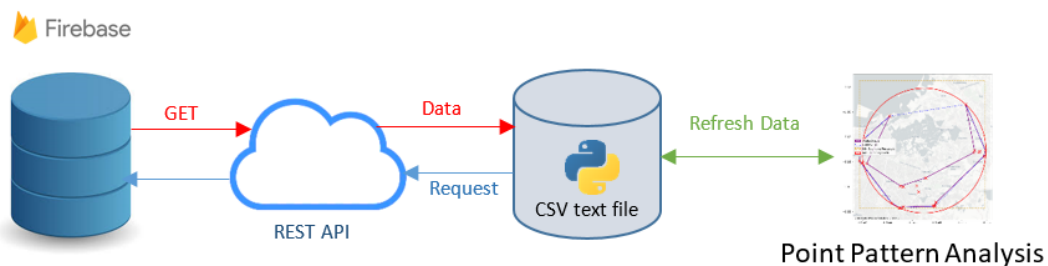


Figure 2 Get real-time data form Firebase and analysis using Point Pattern Analysis

2.3 Data generation

To analyze the point pattern distribution, a simulation was carried out with three scenarios: (1) the addition of an additional point at the edge of an existing cluster, hereinafter referred to as scenario 1; (2) an additional point occurs at the center of an existing cluster, hereinafter referred to as scenario 2; and (3) the addition of a point that creates a new cluster, hereinafter referred to as scenario 3. This simulation was carried out in the city of Makassar, South Sulawesi, Indonesia, involving volunteers using iRTLAMP devices and the IoT button application. Volunteers who participated in this study were not exposed to COVID-19 and only used the device and application as a simulation of the system. Thirty points were generated, and no existing data were used because the priority was to see whether the delivery and analysis process in real time could function properly.

2.4 Data Analysis

Point pattern analysis was carried out to observe changes in the point patterns by examining the distribution of points on the map. Changes in the distribution of points on the map also cause changes in the patterns of these points. By examining the pattern of changes from these points, it is hoped that the nature of the pattern changes resulting from changes in the distribution of points will be understood. In addition, by looking at existing patterns, it is hoped that the spread of COVID-19 can be predicted so that prevention can be carried out

in locations that may become new clusters for the spread of this disease. To determine the distribution of data, the first step was to plot the location of people exposed to COVID-19 on a map to determine the distribution of people exposed to COVID-19 in the form of points. To analyze the density of these points and classify the points in the cluster, this study used several analyses, namely, Kernel Density Estimation (KDE) analysis and centrography. KDE is a method used to estimate the probability of a density function from data. The kernel used in this study was a Gaussian Kernel, which is expressed as follows:

$$KDE_j = \frac{1}{n} \sum_{i=1}^n \frac{1}{h\sqrt{2\pi}} e^{-0.5 \frac{(x_j - x_i)^2}{h^2}} \quad (1)$$

where n is the number of observed data points, h is the bandwidth, x_i are observed data points, and x_j are series of data point where kernel function is calculated.

The next step was centrographic analysis. Centrography is an analytical technique that calculates the center or mean of the spatial distribution of a phenomenon. Given these mean and median points, it is also possible to calculate the distance from the center location when there is a new distribution. The purpose of this analysis was to identify the center of spread.

The mean and median centers are computed as follows:

$$x_{mc} = \frac{1}{n} \sum_{i=1}^n x_i \quad (2)$$

$$y_{mc} = \frac{1}{n} \sum_{i=1}^n y_i \quad (3)$$

while the Euclidean median can be expressed as :

$$\min f(x_{em}, y_{em}) = \sum_{i=1}^n \sqrt{(x_i - x_{em})^2 + (y_i - y_{em})^2} \quad (4)$$

Meanwhile, to calculate the distance between two locations with known longitude and latitude, the haversine formula was used as follows:

$$h = \sin^2(\Delta\phi/2) + \cos\phi_1 \cdot \cos\phi_2 \cdot \sin^2(\Delta\lambda/s) \quad (5)$$

$$c = 2 \cdot \text{atan}^{-1}(\sqrt{h}, \sqrt{1-h})$$

$$d = R \cdot c$$

where λ is longitude and ϕ is latitude and R is equal to 6.371 km (earth's radius).

3. Results

To determine the distribution of the data, the first step was to plot the location of people exposed to the form of points. The initial point distribution was 30 points, as shown in Figure 3a, and three scenarios were used, as shown in Figures 3b, 3c, and 3d, where changes in spatial data were seen in the form of adding points that followed the three scenarios carried out in this study, which are indicated by the red circles. It can be seen from the figure that the points are scattered randomly on the map, showing the distribution locations of people who have been exposed to COVID-19. However, this visualization does not provide sufficient information to clearly observe the distribution pattern because it only describes randomly scattered points.

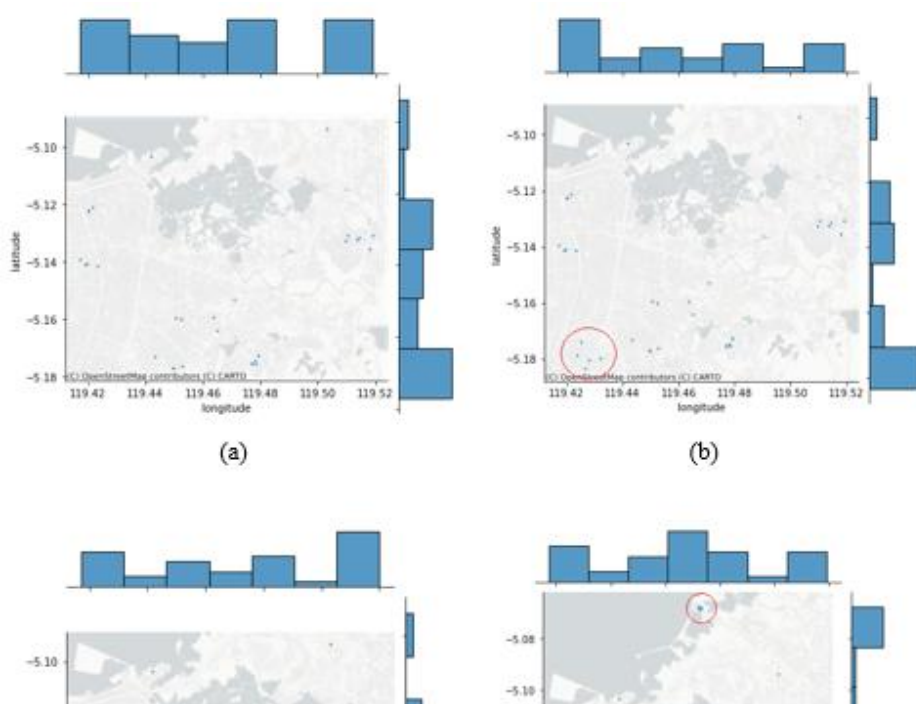


Figure 3 The distribution of exposed to COVID-19 spread on the map in the form of points and changes in spatial data in the form of points by following the third scenario. Changes in spatial data can be seen in the red circle

Furthermore, KDE analysis was performed to determine the difference in density in the cluster areas of the three clusters formed. In addition, the density indicated by the darker color in the center of each cluster also shows a difference. Figure 4b shows the addition of points using Scenario 1, where it can be seen that the cluster at the bottom of the map will widen, which is the impact of adding points to the cluster compared to Figure 4a, which is the initial point distribution. With the addition of a number of points in other clusters using Scenario 2, it can be seen that the density in that cluster changes, which is indicated by a darker color in the center of the cluster, as shown in Figure 4c. Meanwhile, adding points at other locations on the map creates a new cluster, namely the 4th cluster as shown in Figure 4d.

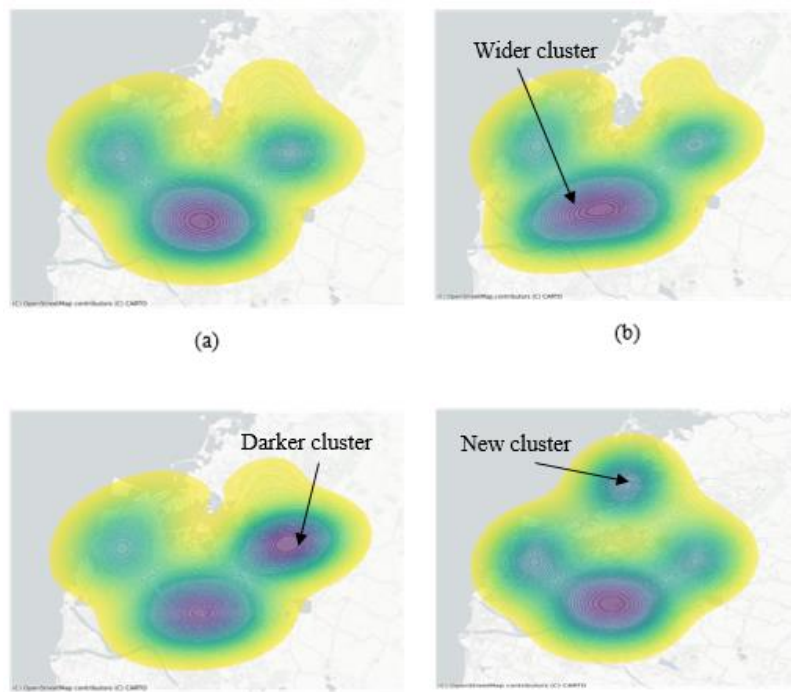


Figure 4 Changes that occur in the cluster using KDE analysis in the three scenarios; (a) initial (b) scenario 1 (c) scenario 2 (d) scenario 3.

From Figure 5, it can be observed that there is a change in the mean and median points when applied to the three scenarios. The mean point represents the average value of the point pattern in the distribution, and the median point represents the middle value of the existing point pattern. Changes in the median and mean points, as well as the distance from the median and mean starting points, based on the three scenarios are shown in Tables 1 and 2.

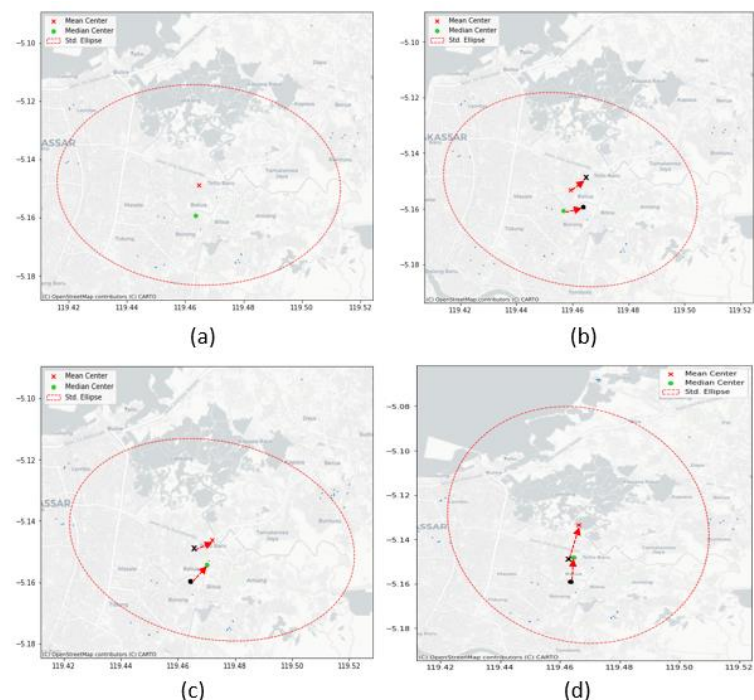


Figure 5 Changes that occur in the cluster using KDE analysis in the three scenarios; (a) initial (b) scenario 1 (c) scenario 2 (d) scenario 3.

Table 1 Longitude and latitude of mean including distance from initial point changes during simulation with three scenarios

	Location		Distance (km)
	Longitude	Latitude	
Initial	119.46463257	-5.14878677	0
Scenario 1	119.45926683	-5.15312129	0.765
Scenario 2	119.47192769	-5.14612440	0.860
Scenario 3	119.46618497	-5.13351557	1.706

Table 2 Longitude and latitude of median including distance from initial point changes during simulation with three scenarios

	Location		Distance (km)
	Longitude	Latitude	
Initial	119.46362200	-5.15918400	0
Scenario 1	119.45676376	-5.16075840	0.780
Scenario 2	119.47017913	-5.15436299	0.902
Scenario 3	119.46472863	-5.14818226	1.230

Furthermore, by using the visual form of the spatial distribution, several types of boundary shapes are used, namely, minimum bounding rectangles, which are made in the form of a boundary in the form of a box that is the minimum box shape or the smallest box area that can be made in the existing spatial distribution. Next, we search for the minimum bounding circle that describes the minimum circle shape with a minimum area that can limit the spatial distribution. In principle, it is almost the same as minimum bounding rectangles with only a limiting shape. The convex hull shape is a line that connects the outermost points of the spatial distribution and never forms a closed pattern within the shape itself. Another shape is the alpha shape, which is a stricter version of the convex hull. It is a line that connects all the outermost points of the spatial pattern and can go back inside itself to form a tighter pattern than the

convex hull. The visual form of this barrier is shown in Figure 6. The pattern of this barrier also seems to change according to the pattern of the three scenarios that have been carried out.

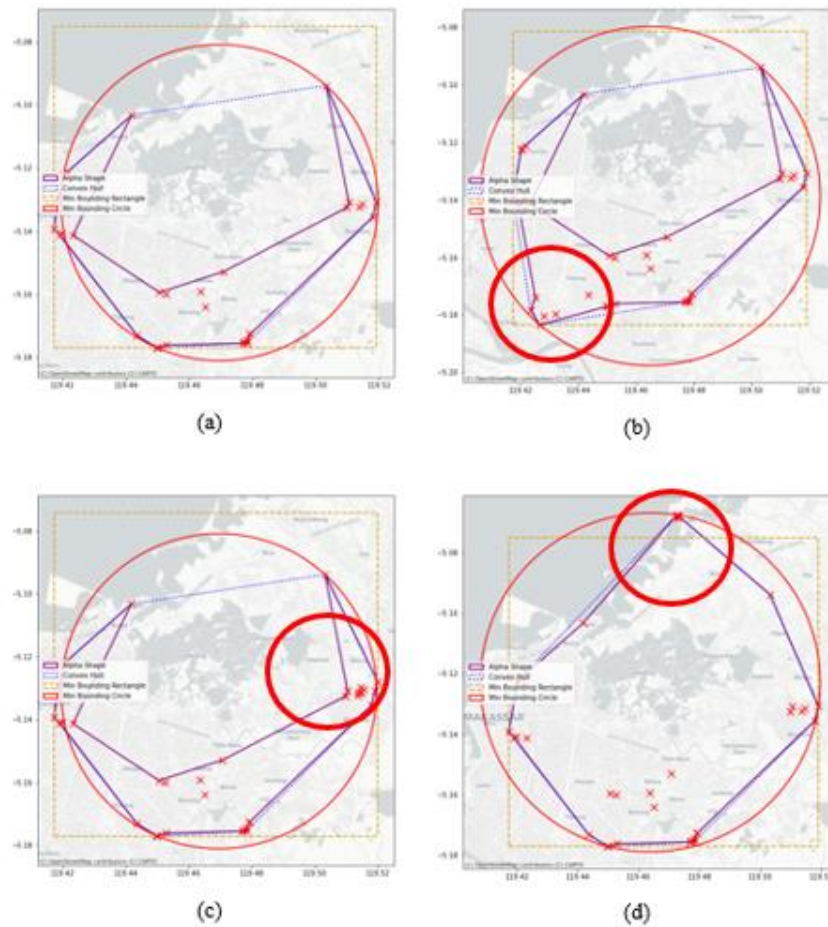


Figure 6 Extent changes during simulation with three scenarios; (a) initial (b) scenario 1 (c) scenario 2 (d) scenario 3.

4. Discussion

Simulations carried out using the developed system showed that the use of IoT devices can help monitor people exposed to COVID-19. The use of GIS can be used to analyse, map and visualise the spread of disease.^{27,28} Analysis carried out with PPA can also show changes in the center and patterns of spread when there is an increase in the number of people exposed to an area. This surveillance was intended to minimize the spread by taking prompt and appropriate actions, such as isolation and providing health assistance in areas where the

number of people exposed is quite large. Some of the problems that may be encountered later are the high price of Internet connections for some people and the incompetence of the public in using the applications created. Intensive and structured socialization of related parties and the community of this system requires further studies that are urgently needed so that this system can be implemented properly and widely. In addition, support from policymakers at the city, provincial, and central levels is needed to encourage this system to be well received by all circles.

5. Conclusions

Identification of the center of spread and analysis of the pattern of the spread of a disease, including COVID-19, is a very important action taken to prevent a greater spread of COVID-19. By knowing the center and pattern of spread, actions such as isolating the place of spread can be carried out quickly. The sooner this information is obtained, the sooner action can be performed. The analysis of the shift in the distribution center provides assistance to related parties to take preventive actions so that new clusters do not appear, which can widen the spread of the disease. The simulation of the monitoring system, central analysis, and distribution pattern in this study shows that a real-time data delivery system and point pattern analysis can provide accurate information. With this system, it is hoped that policymakers at local and national levels will get faster and more accurate information about the phenomenon of the spread of diseases such as COVID-19.

Acknowledgement

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The study was conducted in the city of Makassar, which is located at longitude 119.423790 and latitude -5.135399. Makassar is located on the island of Sulawesi, Indonesia, and has a tropical monsoon climate. Based on the population census in 2020, the total population is around 1,423,877 and a population density of 228,237 people/km² inhabiting 15 sub-districts.²⁴

2.2 System design

A point in the form of spatial data can be seen as two views, namely the position of the point itself and the value that exists at that point. The point spread over certain locations on a map are called point patterns (~~point patterns~~). In the case of the spread of COVID-19, the analysis was conducted using the position of the points spread over several locations on the map with the value of ~~the point itself~~. In this study, the positions of the poin on the map were obtained through 2 devices, namely the internet reverse transcription loop mediated isothermal amplification (iRTLAMP) and the IoT button application shown in Figure 1. iRTLAMP is an RT-LAMP²⁵ device that has been added with Internet of Things (IoT) features on the device

so that it can transmit the position of the device. This device was placed at a hospital and used to detect whether a person had been exposed to COVID-19 by taking a saliva sample from the person who wanted to be tested. If the device detects COVID-19, the IoT module sends the longitude and latitude of the hospital to the cloud database (Firebase) to record the position of the exposed person. Likewise, the IoT Button is an Android-based IoT application that sends the location to the Firebase of the user if the user has been exposed to COVID-19 using other test methods, such as Polymer Chain Reaction (PCR) and antigen. In addition, the main function of this application is to send input data in the form of an identification number (N~~o~~), which is the name of the village that was previously entered during registration. Data in the form of longitude and latitude from these two devices are points on the map to be analyzed.

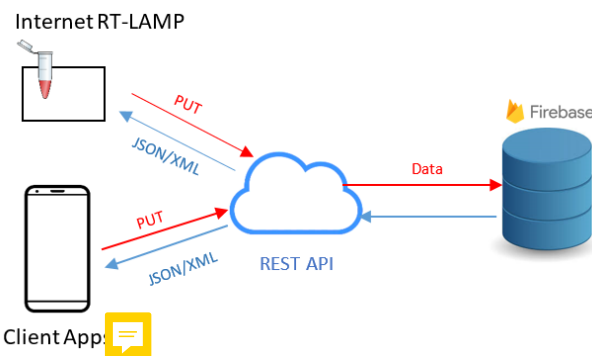


Figure 1 Store real-time data using Android Apps and iRTLAMP

The next step is to create a continuous data retrieval program using the Python programming language and record the results in a CSV format file. The analysis application is also made using Python on the same computer with the data on CSV file and update spatial data in the form of points on a predetermined map which is then analyzed using ~~Point Pattern Analysis~~ (PPA)²⁶ as shown in Figure 2. In general, a program is divided into three categories: delivery, data retrieval, and analysis.

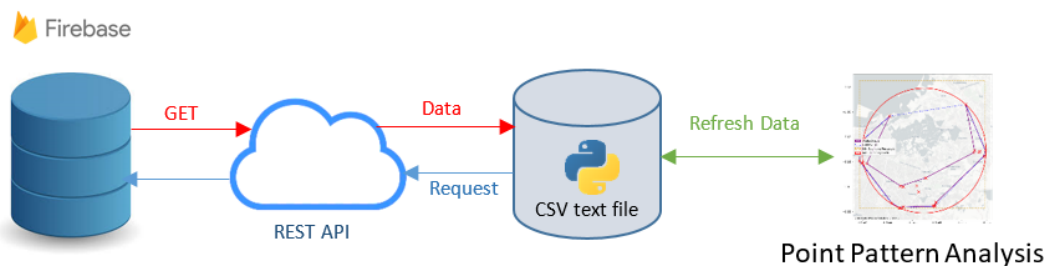


Figure 2 Get real-time data form Firebase and analysis using Point Pattern Analysis

2.3 Data generation

To analyze the point pattern distribution, a simulation was carried out with three scenarios: (1) the addition of an additional point at the edge of an existing cluster, hereinafter referred to as scenario 1; (2) an additional point occurs at the center of an existing cluster, hereinafter referred to as scenario 2; and (3) the addition of a point that creates a new cluster, hereinafter referred to as scenario 3. This simulation was carried out in the city of Makassar, South Sulawesi, Indonesia, involving volunteers using iRTLAMP devices and the IoT button application. Volunteers who participated in this study were not exposed to COVID-19 and only used the device and application as a simulation of the system. Thirty points were generated, and no existing data were used because the priority was to see whether the delivery and analysis process in real time could function properly.

2.4 Data Analysis

Point pattern analysis was carried out to observe changes in the point patterns by examining the distribution of points on the map. Changes in the distribution of points on the map also cause changes in the patterns of these points. By examining the pattern of changes from these points, it is hoped that the nature of the pattern changes resulting from changes in the distribution of points will be understood. In addition, by looking at existing patterns, it is hoped that the spread of COVID-19 can be predicted so that prevention can be carried out

in locations that may become new clusters for the spread of this disease. To determine the distribution of data, the first step was to plot the location of people exposed to COVID-19 on a map to determine the distribution of people exposed to COVID-19 in the form of points. To analyze the density of these points and classify the points in the cluster, this study used several analyses, namely, Kernel Density Estimation (KDE) analysis and centrography. KDE is a method used to estimate the probability of a density function from data. The kernel used in this study was a Gaussian Kernel, which is expressed as follows:

$$KDE_j = \frac{1}{n} \sum_{i=1}^n \frac{1}{h\sqrt{2\pi}} e^{-0.5 \frac{(x_j - x_i)^2}{h^2}} \quad (1)$$

where n is the number of observed data points, h is the bandwidth, x_i are observed data points, and x_j are series of data point where kernel function is calculated.

The next step was centrographic analysis. Centrography is an analytical technique that calculates the center or mean of the spatial distribution of a phenomenon. Given these mean and median points, it is also possible to calculate the distance from the center location when there is a new distribution. The purpose of this analysis was to identify the center of spread. The mean and median centers are computed as follows:

$$x_{mc} = \frac{1}{n} \sum_{i=1}^n x_i \quad (2)$$

$$y_{mc} = \frac{1}{n} \sum_{i=1}^n y_i \quad (3)$$

while the Euclidean median can be expressed as :

$$\min f(x_{em}, y_{em}) = \sum_{i=1}^n \sqrt{(x_i - x_{em})^2 + (y_i - y_{em})^2} \quad (4)$$

Meanwhile, to calculate the distance between two locations with known longitude and latitude, the haversine formula was used as follows:

$$h = \sin^2(\Delta\phi/2) + \cos\phi_1 \cdot \cos\phi_2 \cdot \sin^2(\Delta\lambda/s) \quad (5)$$

$$c = 2 \cdot \text{atan}^{-1}(\sqrt{h}, \sqrt{1-h})$$

$$d = R \cdot c$$

where λ is longitude and ϕ is latitude and R is equal to 6.371 km (earth's radius).

3. Results

To determine the distribution of the data, the first step was to plot the location of people exposed to the form of points. The initial point distribution was 30 points, as shown in Figure 3a, and three scenarios were used, as shown in Figures 3b, 3c, and 3d, where changes in spatial data were seen in the form of adding points that followed the three scenarios carried out in this study, which are indicated by the red circles. It can be seen from the figure that the points are scattered randomly on the map, showing the distribution locations of people who have been exposed to COVID-19. However, this visualization does not provide sufficient information to clearly observe the distribution pattern because it only describes randomly scattered points.

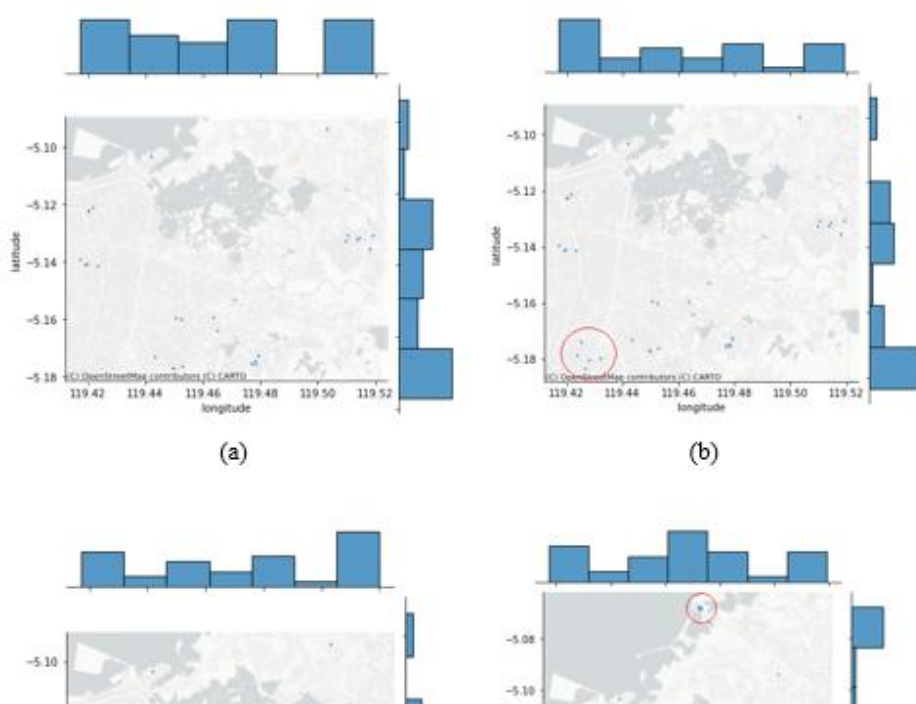


Figure 3 The distribution of exposed to COVID-19 spread on the map in the form of points and changes in spatial data in the form of points by following the third scenario. Changes in spatial data can be seen in the red circle

Furthermore, KDE analysis was performed to determine the difference in density in the cluster areas of the three clusters formed. In addition, the density indicated by the darker color in the center of each cluster also shows a difference. Figure 4b shows the addition of points using Scenario 1, where it can be seen that the cluster at the bottom of the map will widen, which is the impact of adding points to the cluster compared to Figure 4a, which is the initial point distribution. With the addition of a number of points in other clusters using Scenario 2, it can be seen that the density in that cluster changes, which is indicated by a darker color in the center of the cluster, as shown in Figure 4c. Meanwhile, adding points at other locations on the map creates a new cluster, namely the 4th cluster as shown in Figure 4d.

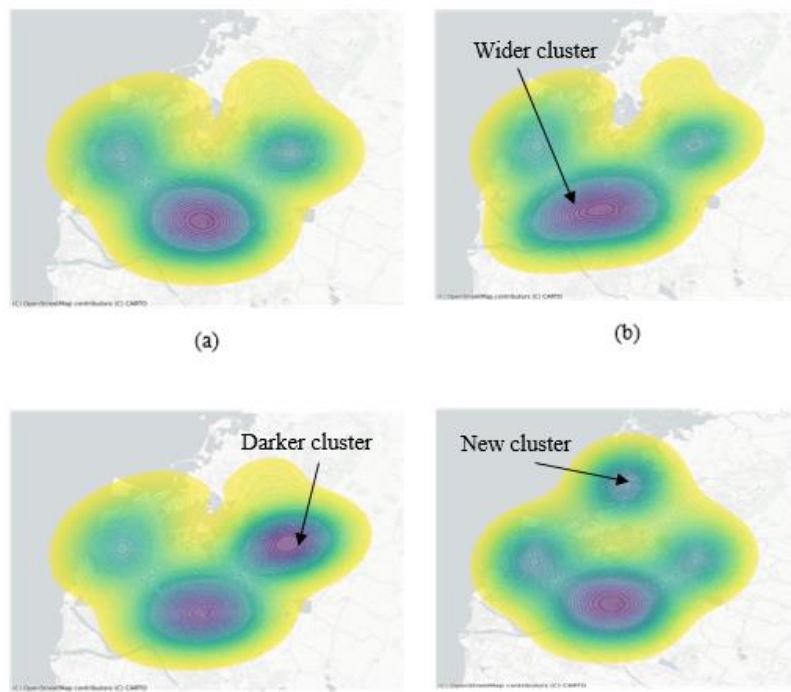


Figure 4 Changes that occur in the cluster using KDE analysis in the three scenarios; (a) initial (b) scenario 1 (c) scenario 2 (d) scenario 3.

From Figure 5, it can be observed that there is a change in the mean and median points when applied to the three scenarios. The mean point represents the average value of the point pattern in the distribution, and the median point represents the middle value of the existing point pattern. Changes in the median and mean points, as well as the distance from the median and mean starting points, based on the three scenarios are shown in Tables 1 and 2.

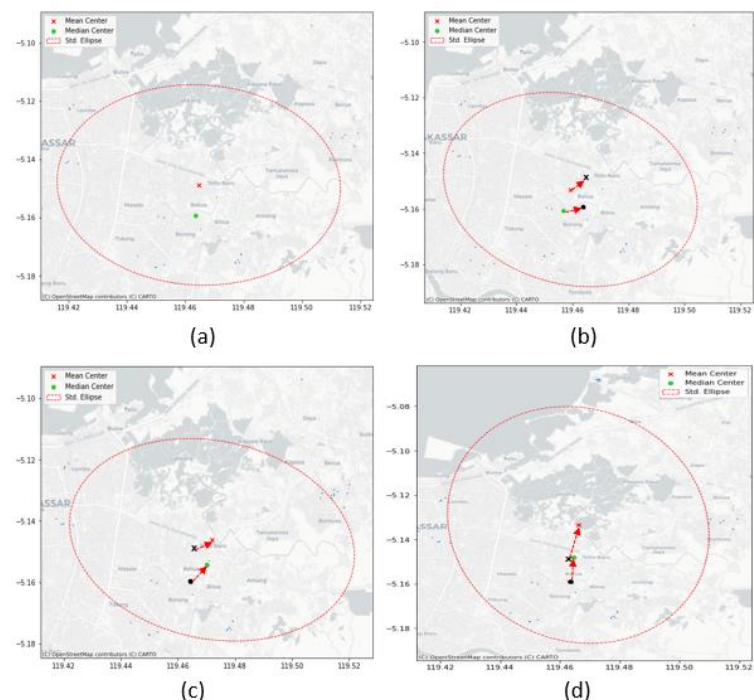


Figure 5 Changes that occur in the cluster using KDE analysis in the three scenarios; (a) initial (b) scenario 1 (c) scenario 2 (d) scenario 3.

Table 1 Longitude and latitude of mean including distance from initial point changes during simulation with three scenarios

	Location		Distance (km)
	Longitude	Latitude	
Initial	119.46463257	-5.14878677	0
Scenario 1	119.45926683	-5.15312129	0.765
Scenario 2	119.47192769	-5.14612440	0.860
Scenario 3	119.46618497	-5.13351557	1.706

Table 2 Longitude and latitude of median including distance from initial point changes during simulation with three scenarios

	Location		Distance (km)
	Longitude	Latitude	
Initial	119.46362200	-5.15918400	0
Scenario 1	119.45676376	-5.16075840	0.780
Scenario 2	119.47017913	-5.15436299	0.902
Scenario 3	119.46472863	-5.14818226	1.230

Furthermore, by using the visual form of the spatial distribution, several types of boundary shapes are used, namely, minimum bounding rectangles, which are made in the form of a boundary in the form of a box that is the minimum box shape or the smallest box area that can be made in the existing spatial distribution. Next, we search for the minimum bounding circle that describes the minimum circle shape with a minimum area that can limit the spatial distribution. In principle, it is almost the same as minimum bounding rectangles with only a limiting shape. The convex hull shape is a line that connects the outermost points of the spatial distribution and never forms a closed pattern within the shape itself. Another shape is the alpha shape, which is a stricter version of the convex hull. It is a line that connects all the outermost points of the spatial pattern and can go back inside itself to form a tighter pattern than the

convex hull. The visual form of this barrier is shown in Figure 6. The pattern of this barrier also seems to change according to the pattern of the three scenarios that have been carried out.

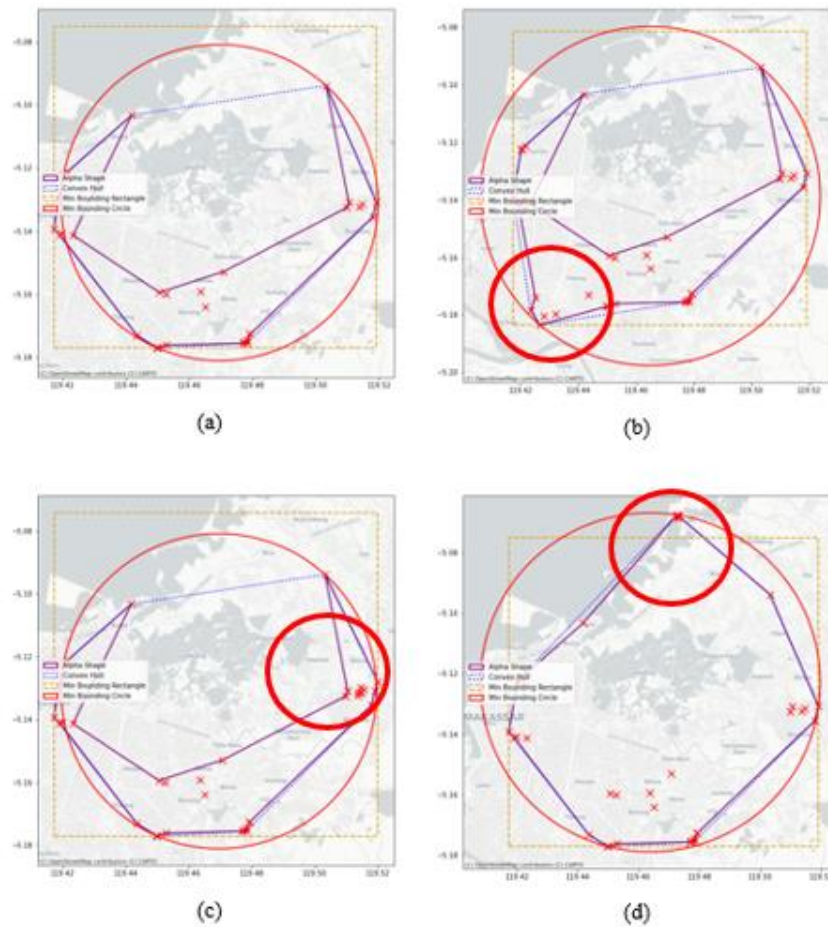


Figure 6 Extent changes during simulation with three scenarios; (a) initial (b) scenario 1 (c) scenario 2 (d) scenario 3.

4. Discussion

Simulations carried out using the developed system showed that the use of IoT devices can help monitor people exposed to COVID-19. The use of GIS can be used to analyse, map and visualise the spread of disease.^{27,28} Analysis carried out with PPA can also show changes in the center and patterns of spread when there is an increase in the number of people exposed to an area. This surveillance was intended to minimize the spread by taking prompt and appropriate actions, such as isolation and providing health assistance in areas where the

number of people exposed is quite large. Some of the problems that may be encountered later are the high price of Internet connections for some people and the incompetence of the public in using the applications created. Intensive and structured socialization of related parties and the community of this system requires further studies that are urgently needed so that this system can be implemented properly and widely. In addition, support from policymakers at the city, provincial, and central levels is needed to encourage this system to be well received by all circles.

5. Conclusions

Identification of the center of spread and analysis of the pattern of the spread of a disease, including COVID-19, is a very important action taken to prevent a greater spread of COVID-19. By knowing the center and pattern of spread, actions such as isolating the place of spread can be carried out quickly. The sooner this information is obtained, the sooner action can be performed. The analysis of the shift in the distribution center provides assistance to related parties to take preventive actions so that new clusters do not appear, which can widen the spread of the disease. The simulation of the monitoring system, central analysis, and distribution pattern in this study shows that a real-time data delivery system and point pattern analysis can provide accurate information. With this system, it is hoped that policymakers at local and national levels will get faster and more accurate information about the phenomenon of the spread of diseases such as COVID-19.

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