A convex hull based geofencing system to eradicate COVID

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ABSTRACT

The World Health Organization (WHO) has identified coronavirus disease (COVID-19), as a global pandemic due to its quick global spread to more than 183 countries. Many countries have used movement control orders (MCO) and high alert levels to halt the spread. The primary goal of this research is to provide a geofencing architecture that is specially tailored to the MCO's standard requirement for monitoring an individual's whereabouts during a lockdown. Whenever an individual tests Corona positive, Geofencing uses technology to notify an anticipated network of people who may be affected and to enable traceability for potential patients. Computational techniques such as Delaunay triangulation (inpolygon) and triangle weight characterization (inside polygon) are applied to analyze the geographical boundary in which the patient is isolated. Convex hull, on the other hand, is a better technique than computational algorithms. It is considered the best mathematical technique because it takes the least amount of time (0.014985 sec) to detect the patient within the geofence layer and has the lowest standard deviation when compared with the other computational techniques.

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1. INTRODUCTION

The epidemic of the corona virus has resulted in a record-breaking demand for online healthcare technology solutions and identified effective ones like population screening, monitoring the illness, planning targeted responses, and prioritizing the usage of resources [1]. Certain strategies are implemented to prevent the increase in rate of the number of patients that include monitoring in advance, frequent tests, tracking the number of contacts, and firm quarantine. The entire process of retracing a virus's path of transmission is known as "contact tracing". It is the current method being used in India and many other nations worldwide to stop the contagious effect of corona virus disease (COVID-19). In a situation that Person A is found to be positive for COVID-19, for instance, it is imperative to follow Persons B, C, and D who have interacted with Person A and place them under a strict quarantine. This is an essential step to take in order to stop the virus's transmission, especially in the initial days. In India, the medical volunteers or health professionals track down every person the patient has spoken to in the previous 14 days who has been in contact with them. The entire system is made up of collectives working together to identify the virus's origin before targeting each potential victim one at a time [2]. The interaction system can endure any pandemic if this entire structure can be substituted by a potential automated risk. With the help of a suitable detection, monitoring and notifying mobile application kit, we may stop the disease from spreading and identify all of the contacts because of promising technological and scientific breakthroughs. As a result, we provide ways to control the current chaos, highlighted with the use of certain trending tools like geofencing and machine learning algorithms [3].

One of the most popular strategies for halting the spread of infectious diseases is quarantine. Social isolation meanwhile focuses on lowering the chances of interaction among people in social places so that they may not get infected by the virus. In March 2020, movement control order (MCO) was being issued by Malaysian Prime Minister. According to a research by Tiwari *et al.* [4], China was able to stabilize at about 80,000 cases after adopting the isolation operations and the usage of applications for spreading awareness in public. Depending on the chosen scenario, geofencing allows an individual or organization to inaugurate notice as well as warnings for either transgressing or entering within that specified area of geofence. A geographic positioning system (GPS) enabled device, application, and person are required for geofencing. Static geofences are fixed for any particular device that is placed at a stationary location [5]. An additional degree of verification is added to the existing encryption process that provides a location-based cryptography approach enabling more intricate uses of location data [6]. In another study, a network of IoT systems for frequency modulation (FM) audio receivers is managed using a geo-fence based on location for song detection [7].

The current techniques undergo various challenges in locating the patient suffering from COVID. Initially, compasses and theodolites were used years ago to determine the patients' location. The health of the patient needs to be protected and personal data sharing should be constrained, at the same time. The method of data collection from various regions varies further causes lack of interoperability between the database and the reporting systems. The existing systems cause delay in notifying the patient's information that further leads to delayed response and lack of resource allocation. Furthermore, inaccurate data also leads to false health actions that are to be taken for patients for further action. Private data regarding the location of the patient can be misused. Another research gap lies in detecting the location in rural areas where the healthcare access is limited. Therefore, the objective of our research is to use a proposed method *i.e.*, convex hull mechanism in order to overcome the existing challenges like removing the overheads, and to build an effective system which is robust to detect the location of the patients that enhances the health response, provides the optimal resource allocation and accurate results.

During the COVID time, geofences played a very important role in the location detection of the affected patients. The patients are required to stay quarantined if they get affected from COVID. The movement of the patients is also being traced. Also, the crowded places are monitored and in case the crowd or gathering is found, it is instructed to be dispersed to reduce the spread of COVID. It also contributed its use in the health authorities by sending the notifications to certain individuals about the breach of the distance in cases they are affected by COVID and to take care by maintaining distance with others.

2. THE COMPREHENSIVE THEORETICAL BASIS

Geofencing is an important technique used widely in the area of location detection algorithms. An important study is carried in [8], where new approaches suggested to advertising apps that use geofence services. This study enhances the location-based searches via an application through location specific services to the practice of generally searching applications using keywords. In order to deliver application suggestions within the geofence area and learn more about the user's location information, geofence approaches are used. In another study, a system warns the users whenever they enter a geofence area [9].

2.1. Framework

A framework is very important in the creation as well as requirement of its functionality for government functions in water supply, power, recycling of waste, freight, and providing service in an economic way and hence achieving social goals [10]. A prerequisite for implementing regional development is the presence of suitable infrastructure [11]. Infrastructure gaps have, however, been brought on by the current uneven distribution of infrastructure. Many construction projects simply pay attention to the city's or a region's economic hub.

2.2. Geofences

A virtual fencing that is constructed to represent a region is called geofencing which is created from numerous geographic boundaries. Many people use geofencing in daily life. For a variety of purposes, numerous geofencing approaches have been created [12], including:

a. Closeness to the object of interest: a geofence is created to find the query point by the creation of a circular zone. This method seeks to determine how close an object is to the object of interest. Only two parameters are used, one being the radius values and other being the center coordinates. As a result, this approach is regarded as the easiest.

b. Adherence to the route and timetable: the prior procedure and this one are nearly identical. However, there are other scheduling techniques with this approach. The time at which the automobile must pass each determined coordinates along the path are provided.
c. Geofenced territory: using this technique, the moving objects in a geofence area are automatically tracked. This virtual boundary is shaped either in the form of a circle or a certain complex figure, like a polygon. Buildings, agricultural fields, and office spaces are all represented by polygons [13].

2.3. Existing work

The below given methods are used to detect the location of the nodes inside and outside the boundary. These techniques help in determining the COVID patients whether they lie within the isolation range or out of the range of isolation. Although these are mathematical algorithms, however, we have used these in determining the location of the patients.

2.3.1. Delaunay triangulation method

A technique for figuring out a coordinate's location is called Delaunay triangulation method. This technique is also known as 'inside polygon' method. By drawing imaginary horizontal lines, it is possible to find out the location of detailed points over a plane. This line is made up of acquired several coordinates. The total number of coordinates that cross over the edge of geofence will then be used to calculate the coordinates. The coordinates are in the polygon region when it is an odd number. The coordinates, however, are outside the geofence when the integer is even [14]. In other words, ray casting is a technique that is employed in computational geometry. It is capable of converting a 2-D scene into a 3-D viewpoint. A ray is directed at the polygon under observation from a certain place. When an endless ray is predicted from any point 'r' towards a specified polygonal fence 'p', this method determines when the query point 'r' is within the polygon or not, as shown in Figure 1. The query point 'r' is inside of 'p' if the limitless ray crosses the odd number of nodes; otherwise, it is outside of p.

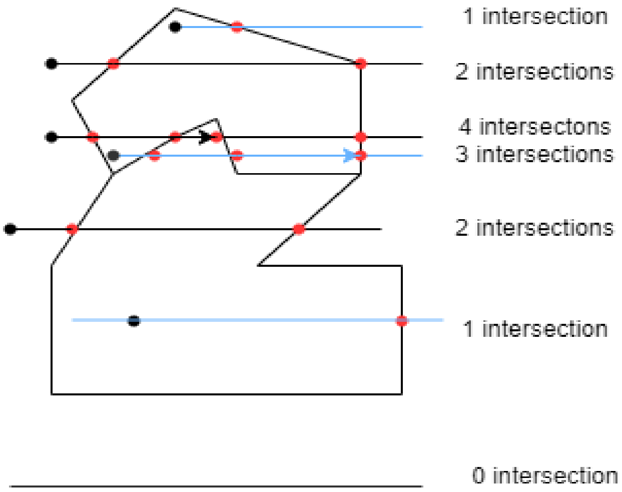

Figure 1. Inside polygon model

A polygon in Figure 1 has an infinite number of rays cast onto it. The connection points are 0, 1, 2, 3, or 4, as shown. Whenever the intersections are odd, this point is shown to be inside the geofence; however, when there are an even number of intersections, it is shown to be outside the polygon.

2.3.2. Triangle weight method

The triangle weight border breach detection method comprises two stages: initialization and run-time. When the system first comes on, both keep-in and keep-out geofences must go through the startup procedure. Any exclusion or inclusion geofence that is amended should be established from scratch if any modifications are made to any of the existing borders. During the initialization process, all the basic boundaries are divided into a straightforward polygonal boundary with y-monotonous polygonal limits, and is finally divided into triangles. The run-time method determines whether each triangle has the interest point. The place is inside the polygon if any of the polygons around the point of interest contain it; if not, it is outside.

A geofence violation occurs whenever the subject is either within the inclusion geofence or out of the exclusion geofence as shown in Figure 2. Any geofence perimeter can be divided into non-intersecting triangles using triangulation approach, which is based on the regularization method. Triangle weight characterization (TWC) method is operated on the triangle, in order to see how a random polygon is divided, as shown in Figure 3. The first step in this initialization procedure is to split the polygon into monotone polygonal boundaries, and the second is to divide each monotone polygonal perimeter into triangles [15]. These operations can all be performed on the x-axis as well, but they are all done with the y-axis in mind.

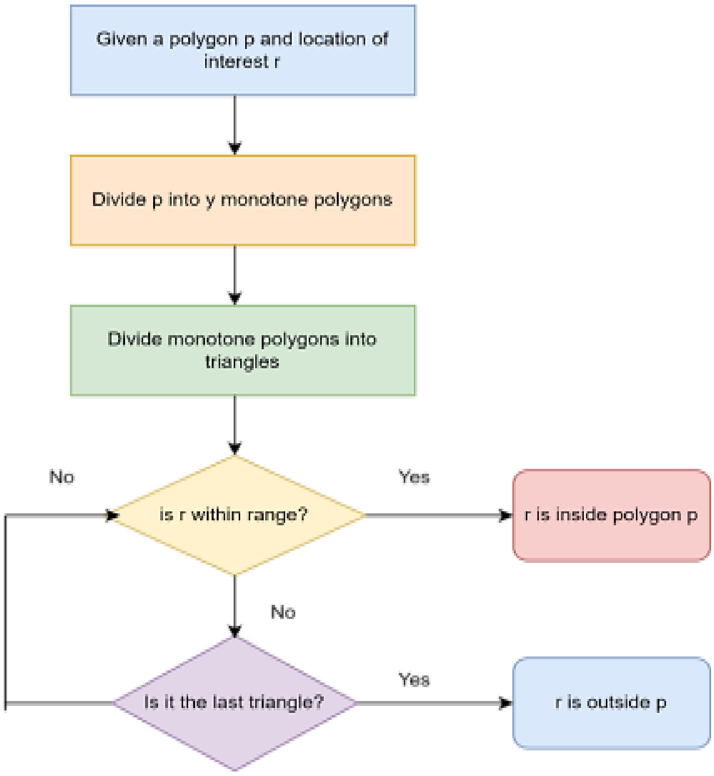

Figure 2. Triangle weight characterization flowchart

a. Polygons into sub-polygons

If all planes parallel to the x-axis do not cross more than two edges of a polygon, it is said to be y-monotone. The monotone polygons are created by creating the linkages between the vertices after iterating the polygonal points from largest to smallest y-location, and then from lowest to highest values of y-location. Geofencing ignores newly added edges that extend beyond the initial polygons because it only takes into account the area covered by the original polygon [16]. It is asserted that the edge sits outside the original polygon when the newly generated polygon's edge vertices are ordered clockwise rather than anticlockwise.

b. Creation of triangles

From largest to lowest y-value, the vertices of each monotone polygon are iteratively repeated while joining edges to form triangles at each step. Due to the fact that they are contained inside y-monotone polygons, all edges that are created are preserved. The example geofence is subjected to this process for five times, where iteration is to be performed for each monotone polygon.

3. PROPOSED APPROACH AND METHODOLOGY

The simulation was carried out in MATLAB and implemented on Microsoft Windows 10, X64 based system with Intel (R) Core (TM) i5 CPU and 8 GB RAM, run on the entities as given in Table 1. The proposed method consumes less time, mean time and standard deviation as compared to the existing methods that are Delaunay triangulation and triangle weight characterization with adjacency (TWCA) (inside polygon).

Table 1. These methods are used to assess if the point is inside or outside the boundary. These techniques do, however, have some drawbacks

S. No.	Entities	Values
1.	Number of nodes	500
2.	Number of tests	200
3.	Number of vertices	10

The following are the TWCA method's drawbacks:

a. Setup and run time stages are present in TWCA. The keep in and keep out geofences must be initialized again if the geofence boundary changes after initialization is complete.
b. TWCA produces inaccurate findings when nodes are dynamic since it is unable to take updates into account with regard to dynamic geofences due to latency.

The following are some drawbacks of the Delaunay triangulation method:

a. An overhead is made while taking the complex polygons into account.
b. For intricate polygons with a greater number of edges, preprocessing is necessary.

Convex hull of points can be used to extend this research because the surface can be split into two half based on x coordinates. A divide and conquer approach are used to calculate the anticlockwise points. The plane's central axis is determined by x's lowest and highest values. The chosen point is joined to the developed axis at its farthest position from the ground. The next point, q, is chosen as the point that performs best when oriented anticlockwise if "configuration $(p, q, r) =$ anticlockwise" is true for any other point r [17]. As a result, each location is continually circled in an anticlockwise manner, and creates a convex hull, as shown in Figure 3. The Delaunay interpolation and TWCA (within polygon) techniques are used to determine if the point is inside or outside the boundary. Determining the greater and lesser slopes of the left and right convex hulls, respectively, will enable you to achieve this. Convex hull algorithm has its advantages over TWCA and Delaunay triangulation because of the following factors:

a. Convex hull does not have different initialization and run time steps hence making it less complicated.
b. Convex hull algorithm gives accurate results for the dynamic nodes.
c. Preprocessing is not necessary for checking the boundary points thus avoiding the overheads.

Algorithm 1. Convex hull

```
Input: Determine a vector of pair 'v' to take query points as the input.
Output: Arrange vector v.
Initialize first element of 'v' as pair 'x'.
Repeat the above steps while one reaches point 'x' again.
Define a pair 'y'that is set to next element of 'v'.
For ith pair of v[i]if [x,v[i],y] have anti clockwise orientation, update value of 'y' as
v[i]. This loop works till the pair with most anti clockwise orientation is found.
end if
end for
Save the output value of 'y' in the vector pair
set 'x'= 'y' for next step
Output is vector of pairs.
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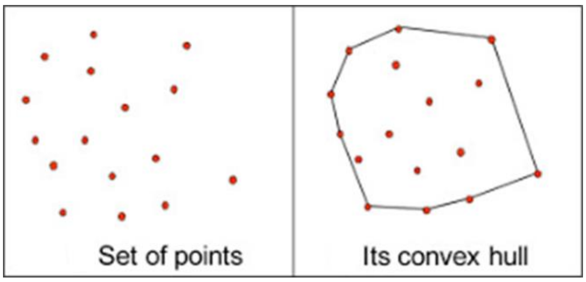

Figure 3. Convex hull

4. RESULTS AND DISCUSSION

The objective of this research is to consume less time, mean time and have least standard deviation by using convex hull method. The experimental method consists of 200 tests, where 500 nodes are used in the area and a geofence is drawn for 10 vertices. The execution time, mean time and standard deviation are considered for the performance of the algorithm to find out which algorithm takes minimum time. This test is run for the algorithms: TWCA, Delaunay triangulation and convex hull. First a geofence is created with 10 vertices on a map and then these algorithms are used to locate the nodes. The geofence boundary is used to determine the nodes whether they lie within the geofence area or outside the geofence area. Real-time location tracking of someone with dementia uses a lot of energy, even while it yields precise findings, [18]. The GPS is used to analyze this in order to provide the precise location. Depending on the need or received signal strength indication (RSSI), that is being handled by the hand- over system, the signal shifts from Wi-Fi to mobile data [19]. However, it causes a certain amount of delay while location detection. In this research, real-time monitoring is not used; instead, boundary or geofence notifications are used to alert us when the boundary is crossed [20]. The construction of geofences allows for more research to be done because the current method requires more time and energy [21].

OpenStreetMaps are used, where the geofences are designed as polygons, where the boundary exit is reported to the authenticated user while taking the boundary violation into consideration [22]. Ten map vertices are used to draw the geofence boundary, as shown in Figure 4. Every time the Triangle Weight algorithm runs, the nodes that is inside the fence as well as any time they cross it are recognized and displayed [23]. Ten vertices are utilized to establish the border in the shape of a polygon, as shown in Figure 4, and they are then used to assess if a node is inside or outside the barrier [24].

Figure 4 also shows the nodes which are inside and outside the geofence boundary when the convex hull approach is implemented. Execution time for the Delaunay triangulation scales linearly with the number of vertex in the geofence [25]. The frequency of location samples has a considerable impact on the projected TWCA execution time. By sampling the location of the vehicle at a higher frequency, it is shown that the average execution time of TWCA does not increase linearly as in Delaunay triangulation but rather is constant independent of the number of geofence points. This data shows that there is still an inverse link between the number of geofence vertex and the percentage of triangles validated, even in the worst recorded cases [26].

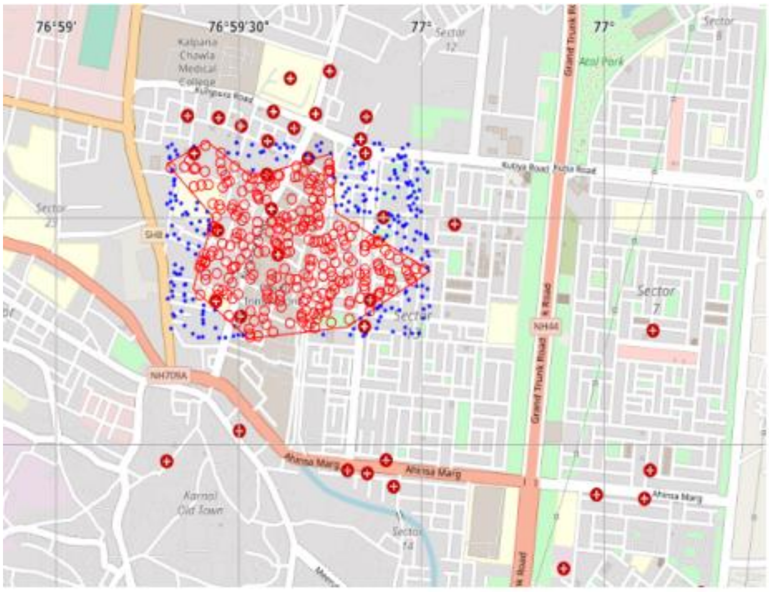

Figure 4. Detecting boundary violation

4.1. Execution time

It is the time taken by the various methods to detect the points within or outside the boundary or polygon, after drawing a geofence boundary. According to Figure 5, convex hull executes 200 tests with 500 nodes and 10 geofence-creating vertices in the shortest amount of time when compared to the map projection and inside polygonal (TWCA) method. Because preprocessing is necessary for complicated polygons with a greater number of edges, Delaunay triangulation incurs expense. Additionally, the execution time grows in direct proportion to the number of triangles and is influenced by more location samples. Figure 6 shows the mean time for all these three mathematical algorithms. Here, it shows that convex hull algorithm has the least execution time of 0.014 sec as compared to Delaunay triangulation and TWCA algorithm.

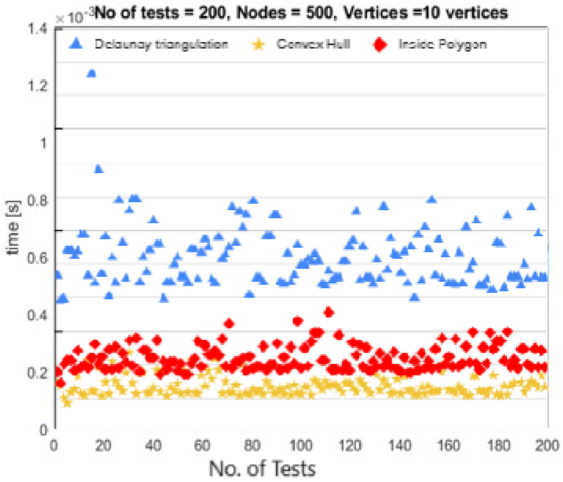

Figure 5. Execution times for Delaunay triangulation (inpolygon), TWCA (inside polygon) and convex hull

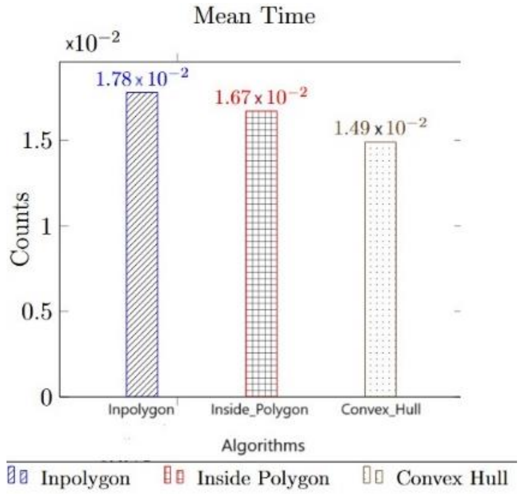

Figure 6. Mean time of Delaunay triangulation (inpolygon), TWCA (inside polygon) and convex hull

4.2. Standard deviation

The standard deviation, referred to as σ, is used to define the measure of the degree of dispersion of the data concerning the mean. A low value of standard deviation determines that the data is concentrated around the mean, whereas a high value of standard deviation shows that the data is more dispersed. A large or small standard deviation, on the other hand, denotes that the data nodes are, respectively, greater or lesser than the mean value. When the standard deviation is close to zero, it indicates that the data points roughly follow the mean.

The measure of deducting each observation from the mean yields the standard deviation. It is determined by computing the mean time. When contrasted with Delaunay triangulation (inpolygon) and TWCA (inside polygon), Figure 7 illustrates that convex hull encompasses the minimum mean time, of 0.014985 sec, hence resulting in low standard deviation, which is further shown in Figure 7.

Figure 7 illustrates how Delaunay triangulation strays as much as possible when attempting to determine whether a node inside the geofence boundary has violated its boundaries. As compared to Delaunay triangulation and inside polygon (TWCA), the convex hull, on the other hand, has the lowest minimum deviation of all the methods due to its short execution time. Additionally, the low standard deviation is a result of the data points being less scattered from the mean.

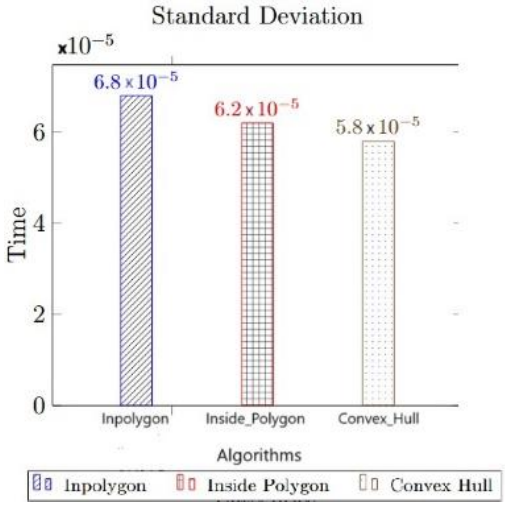

Figure 7. Evaluation of standard deviation of Delaunay triangulation (inpolygon), TWCA (inside polygon) and convex hull

5. CONCLUSION

The web apps and data linkages that make it simpler to develop and manage COVID patients that serve as the basis for location tracking in healthcare sector. This earlier research largely focused on defining geofences, detecting boundary violations, and improving the burden on the family of COVID patients by the use of geofencing, by being aware of staying outside the geofence boundaries and hence preventing themselves from being affected by the virus. Geofence Enforcement software, which is engaged before the boundary is crossed, offers the functionality. Each COVID patient in this study monitors its geofence limits in real-time, allowing it to detect and react to any potential violations. In regard to geofencing, the airspace concept has also been investigated for unmanned aerial vehicles to detect if the airspace stays in the safe boundary and prevents itself from being colliding with another vehicle. Similarly, dementia patients are also tracked by the use of this concept so as to notify the authenticated family member whenever the patient transgresses the boundary. We describe different geofencing boundary violation techniques, such as Delaunay triangulation and TWCA. Additionally, convex hull is proposed and is analyzed to be the best among the existing techniques for figuring out that it takes less mean execution time (0.014985 sec) and has low standard deviation to detect whether the COVID patient is inside or outside the isolated boundary with the help of a virtual fence *i.e.*, geofence.

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