Applications Of Trilateration And Geofencing Techniques In Wireless Network-Based Real Time Asset Location And Tracking In An Indoor Environment

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Abstract— **In this paper, an empirical research on the development of a web application for real-time asset location management system in indoor setting is presented. Specifically, the detailed development of selected key mechanisms of the system is presented. One, the real time indoor asset position detection used trilateration technique to determine the position of assets in indoor areas. Based on this concept, a minimum of three wireless network access points (APs) are used to determine the position of the assets in the x and y coordinates. Three test beds at the main campus of the University of Uyo, Uyo, were carefully selected for the study and they include the computer laboratory, FL3 classroom and engineering workshop. The Ekahau real time location software was used to accomplish the calibration of the test beds. Sample data were used to demonstrate the application of the mechanism in the real-time asset location management web application. The sample asset location detection and tracking performed in each of the selected test beds showed that the x and y location coordinates (in meter) for the asset in each of the test beds are as follows; Computer Laboratory (4.36 , 2.55), FL3 Classroom (- 1.25, 2.24) and Engineering Workshop (4.69, 2.18). Two, the other salient mechanisms presented are geo-location mechanism and geo-fencing mechanism. The geo-location mechanism uses the GPS location coordinates of the asset to visualize the asset's location on Google map. In addition, geo-fencing mechanism is used to mark and track the asset location and movement within and outside the designated indoor region of interest. Sample Google map-based screenshots for the results from the geo-location and geo-fencing mechanisms were also captured as part of the results in the paper. In all, the paper demonstrates the application of electronic and software tools to monitor and track the location of asset in real-time.**

I. Introduction

Nowadays, assets tracking is one of the most attractive technologies. Various technologies are currently used for tracking assets. Particularly, the Global Positioning Systems (GPS) is mainly used for outdoor environment assets tracking applications [1,2,3,4,5]. However, the non-suitability of GPS in indoor conditions because of its non-line of sight (NLOS) conditions and signal attenuation has led to several other techniques for indoor positioning. This work proposes a real-time asset location management system for indoor environment [6,7,8]. Essentially, in this paper, some key mechanisms employed in a web application for real-time asset location management system for indoor environment are presented. One of the key mechanisms is the trilateration localization technique that is used to determine the asset two dimensional location coordinates (x and y coordinates of) within a given test bed area [9,10,11,12,13,14,15,16].The trilateration localization technique estimates an object position based on measured distances of the object from multiple reference points [10, 14, 17, 18]. In this paper the reference points are wireless network access point and the asset is represented by an electronic tag attached to the asset. The electronic tag uses wireless network signal to interact with the network access points, thereby disclosing essential parameters that are used to determine the exact location of the asset. In this paper, the distance of the object is estimated using the measured signal strength received from the electronic tag attached to the mobile object (asset).

In addition, the real-time asset location management system uses geo-location technology [19, 20, 21] to capture GPS location coordinates of asset in real-time, store the GPS coordinates and visualize the locations of the assets on Google map. Furthermore, geo-fencing technology [22,23,24] is also used in the location management system to monitor and give alert when the asset is being taken beyond a defined geographic area. In the succeeding sections, the detailed mathematical expressions for the

trilateration localization technique are presented along with flowchart or procedure for the geo-location and geo-fencing of asset location. Also, results of sample asset location determination using trilateration localization technique are presented. Again, screenshots showing the results of the application of the trilateration localization technique, geo-location and geo-fencing techniques in a real-time asset location management web application are presented.

II. METHODOLOGY

A. TRILATERATION TECHNIQUE

The real-time outdoor location management system considered in this paper entails using geolocation technology to capture GPS location coordinates of asset in real-time, storing the GPS coordinates and visualizing the location on Google map. Furthermore, geo-fencing technology is also used in the asset location management system to monitor and give alert when the asset is being taken beyond a defined geographic area. Most importantly, the asset location management system relies on a localization algorithm to determine the exact location of an asset. The localization algorithm in the study work is the trilateration localization technique. This is based on the laterations process. Considering the basic formula for the general expression for a sphere as shown in Equation (1);

$$d^2 = x^2 + y^2 + z^2 \qquad (1)$$

For a sphere centred at a point (x_a, y_a and z_a), the Equation is simplified as shown as in Equation (2);

$$d^2 = (x - x_a)^2 + (y - y_a)^2 + (z - z_a)^2 \quad (2)$$

Consider the three anchor nodes (a, b and c) with distance (d_a, d_b and d_c)to the blind node as shown in Figure 1.
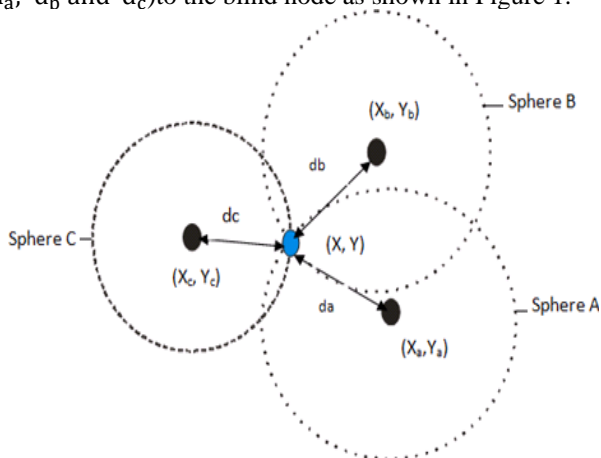

Figure 1: Intersection of three spheres in two-dimensional (2D)

Then, the distances, (d_a, d_b and d_c) for the spheres in a 2D (X and Y) plane are given as:

Sphere A;
$$d_a{}^2 = (x - x_a)^2 + (y - y_a)^2 \qquad (3)$$

Sphere B;
$$d_b{}^2 = (x - x_b)^2 + (y - y_b)^2 \qquad (4)$$

Sphere C;
$$d_c{}^2 = (x - x_c)^2 + (y - y_c)^2 \qquad (5)$$

Equations (3), (4) and (5) when further expanded gives:
$$d_a{}^2 = x^2 - 2x(x_a) + (x_a)^2 + (y)^2 - 2y(y_a) + (y_a)^2 \qquad (6)$$

$$d_b{}^2 = x^2 - 2x(x_b) + (x_b)^2 + (y)^2 - 2y(y_b) + (y_b)^2 \qquad (7)$$

$$d_c{}^2 = x^2 - 2x(x_c) + (x_c)^2 + (y)^2 - 2y(y_c) + (y_c)^2 \qquad (8)$$

Equations (6), (7) and (8) are independent non-linear simultaneous equations which cannot be solved in a closed form. However, using method proposed by Dixon [26] to obtain the radical plane for sphere intersection, Equation (8) was subtracted from Equation (7) to get the following linear Equation:

$$d_b{}^2 - d_c{}^2 = 2x(x_c - x_b) + (x_b)^2 - (x_c)^2 + 2y(y_c - y_b) + (y_b)^2 - (y_c)^2 \qquad (9)$$

Also, subtracting Equation (6) from Equation (7), the following linear Equation is obtained:

$$d_b{}^2 - d_a{}^2 = 2x(x_a - x_b) + (x_b)^2 - (x_a)^2 + 2y(y_a - y_b) + (y_b)^2 - (y_a)^2 \qquad (10)$$

Rearranging Equation (9) gives:
$$x(x_c - x_b) + y(y_c - y_b) = \frac{(d_b{}^2 - d_c{}^2) - ((x_b)^2 - (x_c)^2) + ((y_b)^2 - (y_c)^2)}{2} = V_a \qquad (11)$$

Again, rearranging Equation (10) gives:
$$x(x_a - x_b) + y(y_a - y_b) = \frac{(d_b{}^2 - d_a{}^2) - ((x_b)^2 - (x_a)^2) + ((y_b)^2 - (y_a)^2)}{2} = V_b \qquad (12)$$

Resolve Equation (11) and Equation (12) to gain the intersection point 'x' and 'y' of the two equations gives:

$$y = \frac{V_b(x_c - x_b) - V_a(x_a - x_b)}{[(y_a - y_b)(x_c - x_b)] - [(y_c - y_b)(x_a - x_b)]} \qquad (13)$$

$$x = \frac{V_a - y(y_a - y_b)}{(x_c - x_b)} \qquad (14)$$

The values for x and y gives the accurate position in 2D [9].

B. GEOLOCATION AND GEOFENCING OF ASSET LOCATION COORDINATES FOR OUTDOOR ASSET LOCATION MANAGEMENT

Due to the challenges of interfacing with the available proprietary Ekahau [25] and geolocation data output from mobile devices, a laptop was used to implement a typical interface between the asset location management software (ALMS) and the asset location coordinates capturing technologies. Typically, the laptop with internet access provides the geolocation service and furnishes the ALMS with the geolocation coordinates. In turn, the ALMS process the geolocation data and renders it on a Google map as well as on a tabular view. The interface is shown in Figure 2.
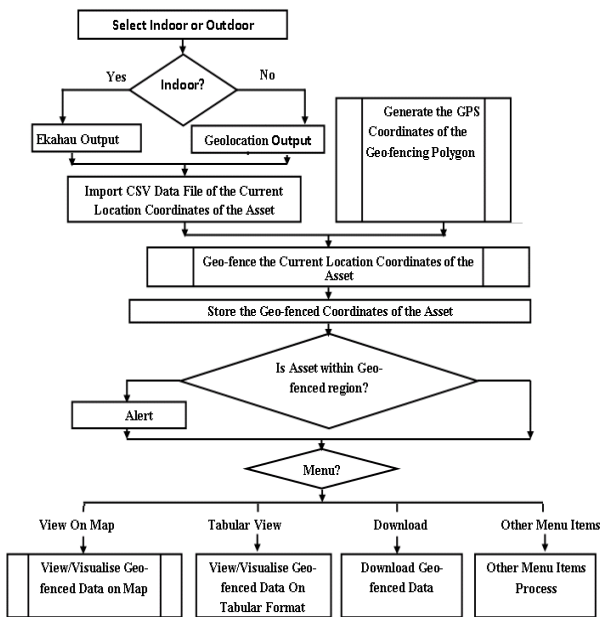
Figure 2: The flowchart for the Geo-location and Geo-fencing of asset location

III. RESULTSAND DISCUSSION

A. RESULTS OF THE TRILATERATION LOCALIZATION

In this paper, three test environment were used and the three test beds are located in faculty of Engineering at the main campus of University of Uyo, Akwa Ibom State. The test beds include :computer laboratory, FL3 classroom and Engineering Workshop.

B. COMPUTER LABORATORY :RESULTS OF THE TRILATERATION LOCALIZATION

Data were taken from three access points AP1, AP2, and AP3.

For AP1,   AP2
         AP3

$x_1 = x_a = 2.1$m $x_2 = x_b = 1.9$m
$x_3 = x_c = 5.25$m
$y_1 = y_a = 2.8$m $y_2 = y_b = 2.2$m
$d_1 = d_a = 1.01$m $d_2 = d_a = 1.42$m
$d_3 = d_c = 1.13$m

Wherex_1, x_2, and x_3 are the distance in the x co-ordinate; y_1, y_2 and y_3 are the distance in the y co-ordinate; and d_1, d_2 and d_3 are the distances between the transmitter and receiver. From the expression given in Equation 11 and the data taken from three access points AP1, AP2, and AP3, then;

$$V_a = V_1$$
$$= \frac{(d_b{}^2 - d_c{}^2) - ((x_b)^2 - (x_c)^2) + \left((y_b)^2 - (y_c)^2\right)}{2}$$

$$V_a = V_1$$
$$= \frac{(1.42^2 - 1.13^2) - (1.9^2 - 5.25^2) - (2.2 - 4.7^2)}{2}$$
$$V_a = V1 = \frac{41.942}{2} = 20.97$$

Also, from Equation 12

$$V_b = V_2$$
$$= \frac{(d_b{}^2 - d_a{}^2) - ((x_b)^2 - (x_a)^2) + \left((y_b)^2 - (y_a)^2\right)}{2}$$

$$V_b = V_2$$
$$= \frac{(1.42^2 - 1.01^2) - (1.9^2 - 2.1^2) - (2.2^2 - 2.8^2)}{2}$$
$$V_b = V2 = \frac{4.7963}{2} = 2.40$$

From the expression given in Equation 13

$$y = \frac{V_b(x_c - x_b) - V_a(x_a - x_b)}{[(y_a - y_b)(x_c - x_b)] - [(y_c - y_b)(x_a - x_b)]}$$

$$y = \frac{2.4(5.25 - 1.9) - 20.97(2.1 - 1.9)}{(2.8 - 2.2)(5.25 - 1.9) - (4.7 - 2.2)(2.1 - 1.9)}$$
$$y = \frac{3.846}{1.51} = 2.55m$$

Also, from Equation 14

$$x = \frac{V_a - y(y_a - y_b)}{(x_c - x_b)}$$
$$x = \frac{20.97 - 2.55(4.7 - 2.2)}{5.25 - 1.9}$$
$$x = \frac{14.595}{3.35} = 4.36m$$

Therefore, the X and Y coordinates based on the three access points in the computer laboratory are 4.36m and 2.55m respectively.

C. FL3 CLASSROOM : RESULTS OF THE TRILATERATION LOCALIZATION

Data were taken from three access points AP1, AP2, and AP3. For AP1, AP2 and AP3;

$x_1 = x_a = 3.25$m; $x_2 = x_b = 1.40$m and $x_3 = x_c = 1.70$m
$y_1 = y_a = 2.65$m; $y_2 = y_b = 1.10$m and $y_3 = y_c = 2.25$m
$d_1 = d_a = 4.19$m ; $d_2 = d_b = 2.34$m and $d_3 = d_c = 2.42$m
$y_3 = y_c = 4.7$m with the dataset, Equation 11 gives;

$$V_a = V1$$
$$= \frac{(2.34^2 - 2.42^2) - (1.4^2 - 1.7^2) - (1.1^2 - 2.25^2)}{2}$$
$$V_a = V1 = \frac{(-0.3808) - (-0.93) - (-3.8525)}{2}$$
$$V_a = V1 = \frac{4.4017}{2} = 2.20 \text{ m}$$

Also, from Equation 12

$$V_b = V2$$
$$= \frac{(2.34^2 - 4.19^2) - (1.4^2 - 3.25^2) - (1.1^2 - 2.65^2)}{2}$$
$$V_b = V2 = \frac{2.3345}{2} = 1.17 \text{ m}$$

From the expression given in Equation 13;

$$y = \frac{1.17(1.7 - 1.4) - 2.2(3.25 - 1.4)}{(2.65 - 1.1)(1.7 - 1.4) - (2.25 - 1.1)(3.25 - 1.4)}$$
$$y = \frac{-3.719}{-1.6625} = 2.24m$$

Also, from Equation 14

$$x = \frac{2.2 - 2.24(2.25 - 1.1)}{1.7 - 1.4}$$

$$x = \frac{-0.376}{0.3} = \quad -1.25 \text{ m}$$

Therefore, the X and Y coordinates for the three access points in the FL3 are
-1.25m and 2.24m respectively

D. ENGINEERING WORKSHOP: RESULTS OF THE TRILATERATION LOCALIZATION

Data for the three access points AP1, AP2 and AP3 were taken as follows: For AP1,AP2 and AP3;
$x_1 = x_a = 4.25$m , $x_2 = x_b = 1.60$m and $x_3 = x_c = 1.80$m
$y_1 = y_a = 3.65$ m , $y_2 = y_b = 1.20$m and $y_3 = y_c = 2.45$m
$d_1 = d_a = 5.60$m   , $d_2 = d_b = 2.96$m and $d_3 = d_c = 3.300$m
Then,

$$V_1 = \frac{(d_2^2 - d_3^2) - (x_2^2 - x_3^2) - (y_2^2 - y_3^2)}{2}$$

$$= \frac{(2.69^2 - 3^2) - (1.6^2 - 1.8^2) - (1.2^2 - 2.45^2)}{2}$$

$$= 2.5$$

$$V_2 = \frac{(d_2^2 - d_1^2) - (x_2^2 - x_1^2) - (y_2^2 - y_1^2)}{2}$$

$$= \frac{(2.96^2 - 5.6^2) - (1.6^2 - 4.25^2) - (1.2^2 - 3.65^2)}{2}$$

$$= 2.39$$

$$Y = \frac{V_2(x_3 - x_2) - V_1(x_1 - x_2)}{(y_1 - y_2)(x_3 - x_2) - (y_3 - y_2)(x_1 - x_2)}$$

$$= \frac{2.39(1.8 - 1.6) - 2.54(4.25 - 1.6)}{(3.65 - 1.2)(1.8 - 1.6) - (2.45 - 1.2)(4.25 - 1.6)}$$

$$= \frac{-6.146}{-2.823}$$

$$= 2.18 \text{m}$$

$$X = \frac{V_1 - y(y_3 - y_2)}{x_3 - x_2}$$

$$= \frac{2.5 - 2.18(2.45 - 1.2)}{1.8 - 1.6}$$

$$= 4.69 \text{m}$$

Therefore, the X and Y coordinates for the three access points in the engineering workshop are 4.69m and 2.18m respectively.

Table 1: Test beds and its corresponding coordinates

Test Beds	x (m)	y (m)
Computer Laboratory	4.36	2.55
FL3 Classroom	- 1.25	2.24
Engineering Workshop	4.69	2.18

E. THE RESULTS OF THE APPLICATION OF THE TRILATERATION LOCALIZATION TECHNIQUE, GEO-LOCATION AND GEO-FENCING IN A REAL-TIME ASSET LOCATION MANAGEMENT WEB APPLICATION

The home page of the real-time asset location management web application is given in Figure3. The home page shows the location of some of the assets in the system on the map with info window that displays the properties of a sample highlighted asset. Also, the list of some of the assets captured by the system and their features are shown in Figure 4. The features include name, location, date captured, time of capture, longitude, latitude as well as the current status.
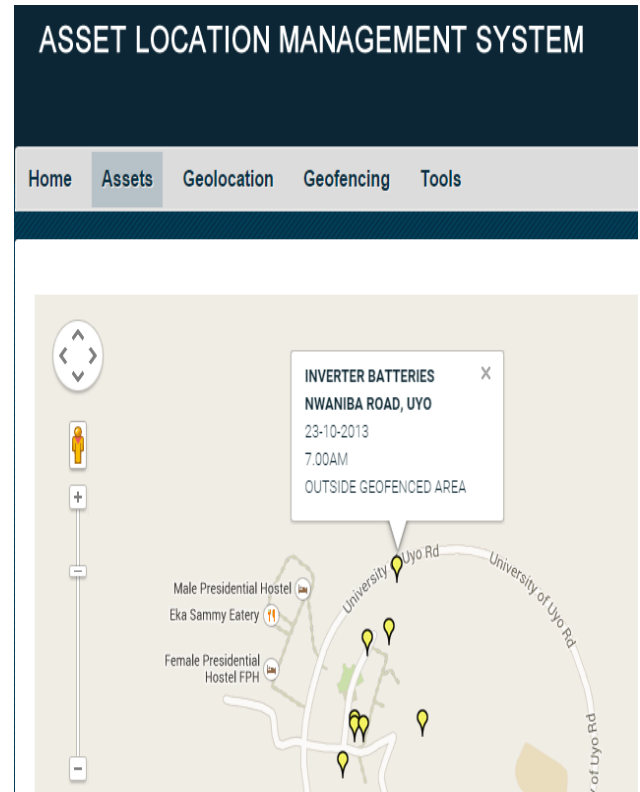

Figure 3: The homepage of the real-time asset location management web application showing asset locations shown on the map.

S/n	Name	Location	Date	Time	Latitude	Longitude	Status
1	2kva Inverter	Nwaniba Road, Uyo	01-01-2012	2.00pm	5.040900	7.974867	Within geofenced area
2	Electronic Digital Meter	Nwaniba Road, Uyo	02-05-2013	4.00pm	5.040900	7.975071	Within geofenced area
3	UPS	Nwaniba Road, Uyo	07-06-2014	5.00pm	5.040355	7.974610	Outside geofenced area
4	Desktop PC 1	Nwaniba Road, Uyo	08-09-2014	9.00pm	5.042236	7.975146	Within geofenced area
5	Laptop	Nwaniba, Uyo	12-Oct-2014	8.00am	5.040996	7.976348	Within geofenced area
6	Laptop 2	Nwaniba, Uyo	12-Oct-2014	9.00am	5.042396	7.975618	Within geofenced area
7	Inverter Batteries	Nwaniba Road, Uyo	23-10-2013	7.00am	5.043369	7.975790	Outside geofenced area
8	Desktop PC 2	Nwaniba Road, Uyo	23-10-2014	4.00pm	5.040996	7.974867	Within geofenced area

Figure 4: Screenshot of assets and their features.

In a situation whereby due to some hitches, the location and features of asset cannot be automatically captured and

saved, the system provides an interface (Figure 5) for manually inputting the features of an asset into the system database.

Figure 5: Screenshot showing a form to add an asset and its location features

Figure 6: Geo-fenced region which is the engineering lab.

The screenshot in Figure 6 shows the geo-fenced region or area which is the Engineering Laboratory that includes the Computer Engineering Laboratory which is located in the main campus of University of Uyo. Furthermore, Figure 7 shows a screenshot of the geo-fenced tool for setting the coordinates of a geo-fenced area.

Figure.7: Screenshot showing the geo-fenced tool.

Once the coordinates of the geo-fenced area are set, the area is marked out on the map by the real-time asset location management system (RTALMS). If an asset is moved (that is, the location of the asset changes) the RTALMS will indicate whether the asset is within a given geo-fenced area or not. For instance, the screenshots of Figure 8 shows an asset that is within a geo-fenced region and Figure 9 shows an asset that is outside a geo-fenced region
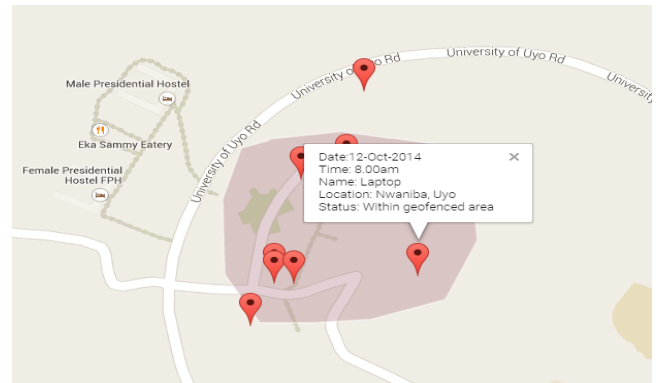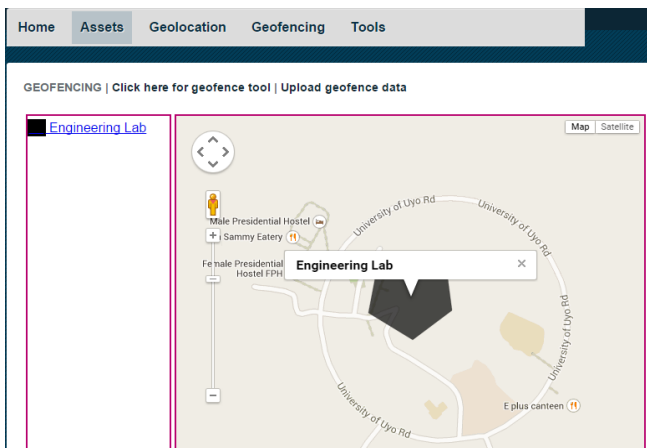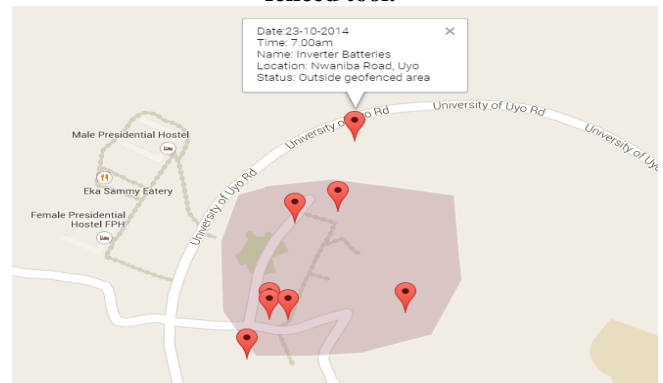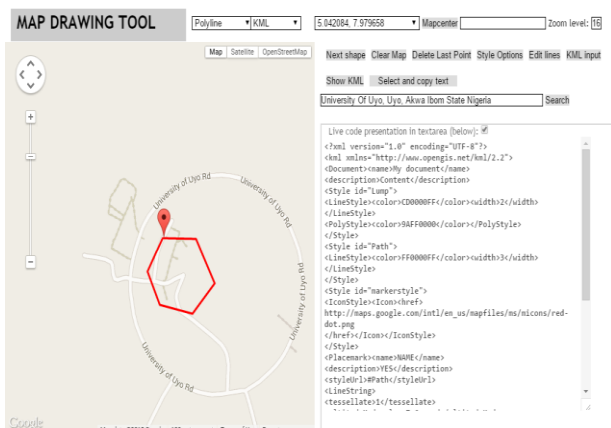.

Figure.8: Screenshot showing the asset within the geo-fenced tool.

Figure.9 Screenshot showing the asset outside the geo-fenced tool.

In practice, the real-time asset location management system (RTALMS) does support one or more geo-fenced regions and at any given time each asset is associated with one particular geo-fenced region which indicates its current resident region. If the asset is moved (that is, the location of the asset changes) the RTALMS will indicate whether the asset is within its given geo-fenced resident region or outside the resident region. In the case where the asset is outside the resident region the RTALMS will sound an alarm to signal unauthorized movement of the asset.

Essentially, before an asset can be moved out of its resident region, personnel with the requisite privilege the RTALMS will disable the assigned resident region status of the asset before it can be moved out of the region. This is because, in the real life situation, the door locking system of the region may be integrated with the RTALMS such that it will not permit the door that leads to the outside of the building to be opened if the system alarm is activated.

IV. CONCLUSION

An empirical research on the development of a real-time asset location management system for an indoor setting is presented. Details of some salient mechanisms of the system are presented. One of such mechanisms is the trilateration localization mechanism for determining the X

and Y coordinates of an asset in real-time. Other mechanisms presented are geo-location mechanism which uses the GPS location coordinates of asset to visualize the asset location on Google map. In addition, geo-fencing mechanism is used to mark and track the asset location and movement within and outside a designated region of interest. Sample data were used to demonstrate the application of the listed mechanisms in the real-time asset location management web application.

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