Satellite Coordinate Transformation: Case Study Of Norad Two Line Element To Cartesian Position Vector Conversion For Nigeriasat X And Alsat 1N Satellites

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***Abstract*—In this paper, satellite coordinate transformation from the popular NORAD Two Line Element (TLE) to Cartesian position vector for NigeriaSat X and ALSAT 1N satellites are presented. The TLE data for the two case study satellites are obtained from https://www.n2yo.com/database. Also, the tracking map imagery of the case study satellites are presented and obtained from the online portal available at : https://www.n2yo.com/. The detailed mathematical formulas for the transformation of the TLE data of the satellites to the Cartesian coordinate are presented along with numerical examples based on the TLE data of the two case study satellites. The results showed that for the NigeriaSat X Low Earth Orbit (LEO) satellite that belongs to Nigeria, the Cartesian position vector (x ,y,z) are (-3,883.71,-2,785.63 ,5,227.05) spectively while for ALSAT 1N cube satellite that belongs to Algeria, (x,y,z) are (132.22, -7049.32, 34.36) respectively. The ideas presented in the study is useful for tracking of satellites and visualization of the satellite track on its orbit.**

Keywords— Satellite , Cartesian Position Vector, NORAD Two Line Element, ALSAT 1N , Coordinate Transformation, NIGERIASAT X, Low Earth Orbit (LEO)

1. Introduction

Satellite communication system is a form of wireless communication system whereby a satellite located in an orbit communicates with an earth station or with another satellite in orbit [1,2,3,4,5,6,7,8,9,10]. Like every other wireless systems, satellite signals can be affected by obstacles in the path of the wireless signal. Also, in the absence of obstacles, the signal strength can still degrade due to free space path loss which is a function of the path length and signal frequency [11,12,13,14,15,16,17,18,19,20,21]. As such, accurate estimation of the signal path length and frequency is essential for analysing satellite communication system.

Furthermore, satellites move in their orbit, thereby changing their position relative to the devices or systems they are communicating with [22,23]. Accordingly, as a satellite moves along its orbit, accurate tracking of its position at any instance is essential. As such, today, advancements in satellite technologies have made it possible to accurately track satellites in their orbit. This capability has made it possible to effectively manage the monition of the satellites and also effectively utilise the satellite commination with various earth station devices and systems. The ability to track the satellite depends on the proper knowledge of the satellite coordinates [24,25,26,27,28,29,30].

In practice, there are many different coordinate systems used in describing the instantaneous location of the satellites [31,32,33,34,35]. Each of the satellite coordinates system is suitable for different applications of the satellite. In many cases, there is need for satellite coordinate transformation for ease of computation or application or visualization of the satellite in its orbit relative to the earth station or relative to other satellites [36,37,38,39,40]. Accordingly, this paper presented satellite coordinate transformation from the NORAD two line element system to the Cartesian position vector coordinate system [41,42,43]. The coordinates of two case study satellites, namely, NigeriaSat X and ALSAT 1N satellites were used for numerical examples.

2. Methodology

The coordinate transformation from NORAD Two Line Element (TLE) to Cartesian position vector form is presented using the TLE data of a study satellite, namely, NIGERIASAT X. Notably, the NIGERIASAT X is a Low Earth Orbit (LEO) satellite with Two Line Element Set (TLE) data shown in Figure 1 while the tracking map imagery is given in Figure 2.

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Two Line Element Set for NIGERIASAT-X

1 37790U 11044C   22182.87050765  .00000079  00000+0  26263-4 0  9997
2 37790  97.8909 224.4261 0011785 200.4527 159.6203 14.58751748579178
```

Figure 1 The Two Line Element Set (TLE) data for NIGERIASAT X (Source: https://www.n2yo.com/satellite/?s=37790)

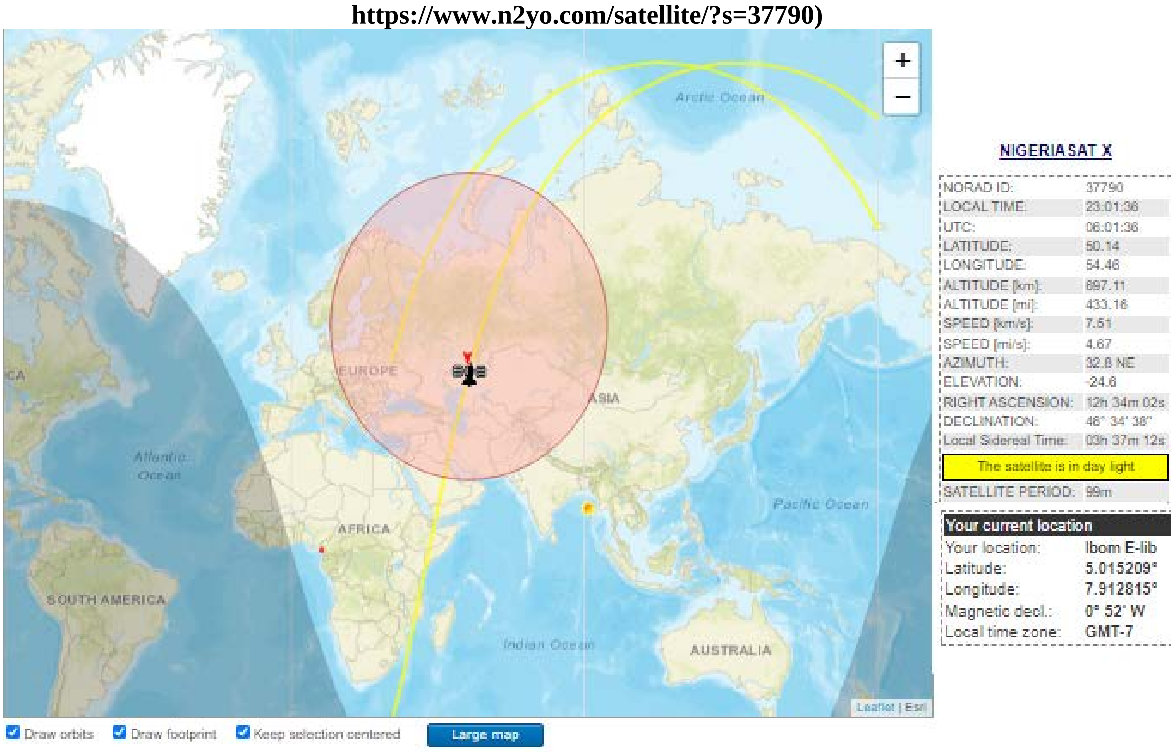

Figure 2 Tracking map imagery of NIGERIASAT X
(available at : https://www.n2yo.com/?s=37790&live=1)

Based on the TLE data for NIGERIASAT X , the following parameters are extracted :

i. The orbit inclination angle (i) in degrees is 97.8909°
ii. The right ascension of the ascending node (Ω) in degrees is 224.4261°
iii. The orbit eccentricity (e) is 0.0011785
iv. The argument of the perigee (ω) in degrees is 200.4527°
v. The mean anomaly (M) in degrees is 159.6203°
vi. The mean motion (n) in revolutions per day is 14.58751748
vii. Revolution number at epoch (N_{ap}) is 57917

The orbital period, T is given as

$$\mathbf{T} = \frac{1}{n} \qquad (1)$$

With n = 14.58637589 rev/day, then

$$\mathrm{T} = \frac{1}{n} = \frac{1}{14.58751748}$$

T = 0.06855176 days = 1.645242244 hours = 98.71453467minutes

The semi major axis, a is given as,

$$\mathbf{a} = \sqrt[3]{\left(\left(\frac{\mathrm{GM}}{4\pi^2}\right)T^2\right)} \qquad (2)$$

Where GM = 2.9755364x$10^{15} km^3/day^2$. Hence,

$$\mathbf{a} = \sqrt[3]{\left(\left(\frac{2.9755364\mathrm{x}10^{15}}{4(3.141592654)^2}\right)(0.06855176\,)^2\right)} = 7075.34439$$

km

The semi minor axis, b is given as,

$$\mathbf{b} = \sqrt[2]{\mathbf{a^2(1-e^2)}} \qquad (3)$$

With e = 0.0011785, becomes;

$$\mathbf{b} = \sqrt[2]{(7075.34439)^2(\mathbf{1}-(0.0011785)^2)} = 7075.339478$$

km

The eccentricity anomaly, E is given as,

$$\mathbf{E} = \mathbf{M} + \mathbf{e}(\mathbf{sin}(E)) \qquad (4)$$

With M = 159.6203° = 2.785899788 radians and e = 0.0011785, E is determined using iterative method and the solution gave, E = 207.7504° = 3.625928502 radians.

$$\boldsymbol{x}''' = (\mathbf{a})\,\mathbf{cos}(\boldsymbol{E}) - (\mathbf{a})\boldsymbol{e} \qquad (5)$$

$$\boldsymbol{y}''' = (\mathbf{b})\,\mathbf{sin}(\boldsymbol{E}) \qquad (6)$$

$$\boldsymbol{z}''' = \mathbf{0} \qquad (7)$$

$\boldsymbol{x}''' =$ $(7075.34439)\,\mathbf{cos}(3.625928502) -$ $(7075.34439)(0.0011785)$ = -6,269.91

$\boldsymbol{y}''' = (7075.339478\,)\,\mathbf{sin}(3.625928502) =$ -3,294.42

$\boldsymbol{z}''' = \mathbf{0}$

$$\boldsymbol{x}'' = (\boldsymbol{x}''')\,\mathbf{cos}(\boldsymbol{\omega}) - (\boldsymbol{y}''')\,\mathbf{sin}(\boldsymbol{\omega}) \qquad (8)$$

$$\boldsymbol{y}'' = (\boldsymbol{x}''')\,\mathbf{sin}(\boldsymbol{\omega}) + (\boldsymbol{y}''')\,\mathbf{cos}(\boldsymbol{\omega}) \qquad (9)$$

$$z'' = z''' \quad (10)$$

$x'' =$
$(-6{,}269.91)\cos(\mathbf{3.49855961}) -$
$(-3{,}294.42)\sin(\mathbf{3.49855961})$=4,723.47
$y'' =$
$(-6{,}269.91)\sin(\mathbf{3.49855961}) +$
$(-3{,}294.42)\cos(\mathbf{3.49855961})$ = 5,277.67
$z'' = \mathbf{0}$

$$x' = x'' \quad (11)$$
$$y' = (y'')\cos(i) - (z'')\sin(i) \quad (12)$$
$$z' = (y'')\sin(i) + (z'')\cos(i) \quad (13)$$

x' = 4,723.47
$y' =$
$(5{,}277.67\ )\cos(\mathbf{1.709403395}) -$
$(\mathbf{0})\sin(\mathbf{1.709403395})$ = -729.18
$z' =$
$(5{,}277.67)\sin(\mathbf{1.709403395}) +$
$(\mathbf{0})\cos(\mathbf{11.709403395})$ = 5,227.05

$$x = (x')\cos(\Omega) - (y')\sin(\Omega) \quad (14)$$
$$y = (x')\sin(\Omega) + (y')\cos(\Omega) \quad (15)$$
$$z = z' \quad (16)$$

$x =$
$(4{,}723.47)\cos(\mathbf{3.916974372}) -$
$(-729.18)\sin(\mathbf{3.916974372})$ = -3,883.71
$y =$
$(4{,}723.47)\sin(\mathbf{3.916974372}) +$
$(-729.18)\cos(\mathbf{3.916974372})$ =**-2,785.63**
z = 5,227.05

The Cartesian coordinates for the satellite is then (x , y, z) =(−3,883.71, −2,785.63 , 5,227.05)

2.2 Coordinate transformation for ALSAT 1N Cube Satellite

The ALSAT 1N is a cube satellite that belongs to the of people Algeria with Two Line Element Set (TLE) data as shown in Figure 2 while the tracking map imagery is given in Figure 4.

Two Line Element Set (TLE):

```
1 41789U 16059G   21218.93182754  .00000076  00000-0  23024-4 0  9991
2 41789  97.9659 271.1136 0029649  72.7581 287.6858 14.64441965259832
```

Source of the keplerian elements: AMSAT

FIGURE 3 THE TWO LINE ELEMENT SET (TLE) DATA FOR ALSAT 1N
I. (SOURCE: HTTPS://WWW.N2YO.COM/SATELLITE/?S=41789)

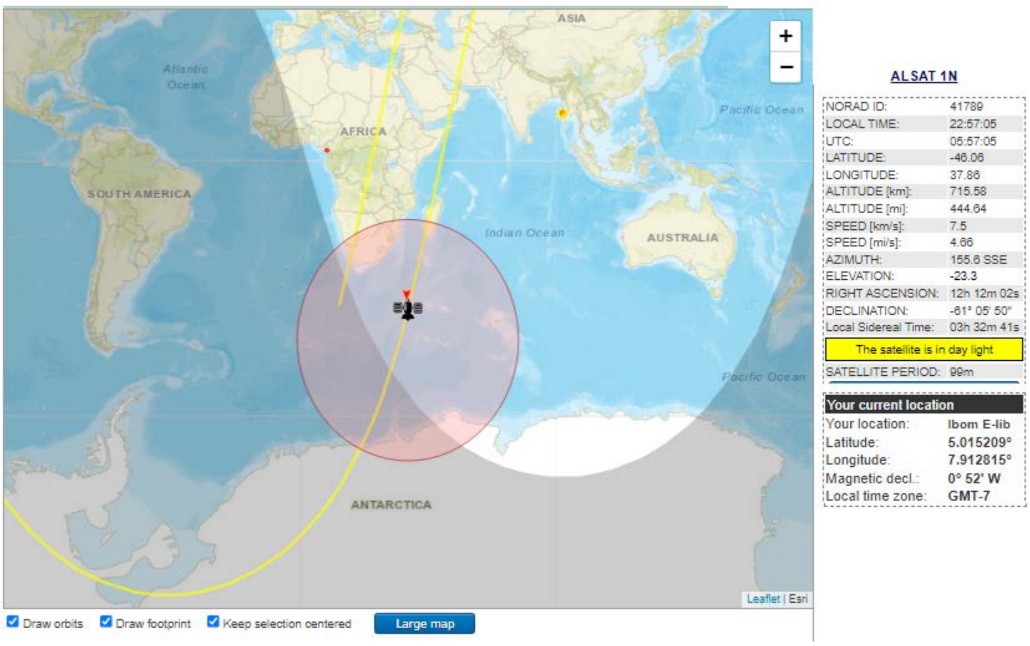

Figure 4 Tracking map imagery of ALSAT 1N
(available at : https://www.n2yo.com/?s=41789&live=1)

Based on the TLE data for ALSAT 1N, the following parameters are extracted :

i. The orbit inclination angle (i) in degrees is is 97.9659 °
ii. The right ascension of the ascending node (Ω) in degrees is 271.1136 °
iii. The orbit eccentricity (e) is 0.0029649

iv. The argument of the perigee (ω) in degrees is 72.7581°
v. The mean anomaly (M) in degrees is 287.6858°
vi. The mean motion (n) in revolutions per day is 14.64441965
vii. Revolution number at epoch (N_{ap}) is 25983

The orbital period, T is

T = 0.068285396 days = 1.638849512 hours = 98.33097073 minutes

The semi major axis, a is **a** = 7057.00459 km

The semi minor axis, b is **b** = 7056.9736 km

The eccentricity anomaly, E is given as,

With M = 287.6858° = 5.021064421 radians and e = 0.0029649, E is determined using iterative method and the solution gave, E = 287.6858° = 5.021064421radians.

$x''' = 2{,}122.97$

y''' = -6,723.44

$z''' = 0$

x'' = 7,050.56

y'' = 34.70

$z'' = 0$

$x' = 7{,}050.56$

y' = -4.81

z' = 34.36

x = 132.22

y = -7,049.32

$z = 34.36$

The cartesian coordinates for the satellite is then $(x, y, z) = (132.22, -7049.32, 34.36)$

3. Conclusion

The coordinate transformation from NORAD Two Line Element (TLE) to Cartesian position vector form is presented for two case a study satellites, namely, NIGERIASAT X that belongs to Nigeria and ALSAT 1N cube satellite that belongs to Algeria. The detailed mathematical formulas for the transformation of the TLE data of the satellites to the Cartesian coordinate are presented along with numerical examples based on the TLE data of the two case study satellites. The ideas presented in the study is useful for tracking of satellites and visualization of the satellite track on its orbit.

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