

## SATELLITE TRACKING USING NORAD TWO-LINE ELEMENT SET FORMAT

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***Abstract:** This paper presents the study of satellite tracking using the NORAD Two-Line Element (TLE) set format. In this research, the mathematical model for the determination of the osculating orbital elements of the selected satellite is presented and one computer program is developed for the satellite tracking using the application Matlab, a platform for solving engineering and scientific problems. The NORAD TLE represents the input data for the developed program, while the output data takes the form of a graphical representation of the satellite track around planet Earth.*

***Keywords:** satellite tracking, NORAD, two-line element, orbital elements, Matlab, application*

### 1. INTRODUCTION

The Space Age started with Sputnik 1's lonely 3 month journey in orbit around Earth. Thus, October 4, 1957 became the first step to space exploration. Starting with this point, many more spacecraft – unmanned and, later, manned – have followed and created history for mankind. History which is now described as satellites into Earth's orbit, around and on the Moon, around the Sun or other planets of our Solar System, and even going further and breaking the boundaries towards other Systems in our Universe [1].

Thus, for young researchers who did not witness this history in its making, two questions appear: how many objects of any kind are in space and who keeps track of them. The answer to the first question is: 1071 operational satellites in orbit around Earth – with more than 50% launched and places into orbit by the United States – and over 170 million space debris objects with dimensions larger than 1 mm – from which 670000 objects are larger than 10 mm and 29000 objects larger than 100 mm [2]. Of course, the numbers are rising from one month to another as more and more countries have joined in on this space race, and furthermore, private companies are developing programs for future space tourism.

While the first question has a simple answer, the second proves to be quite a challenge even with the increasing number of applications dedicated towards satellite and space debris tracking [3]. Although these applications are proving to be a step forward in objects tracking around Earth and not only, they can be used only by experts who possess the theoretical knowledge and practical background and are not suited for common use.

The current paper presents the development and usage of one application for satellite tracking around Earth. The mathematical model for the determination of the osculating orbital elements of the selected satellite is presented and one simple computer program is developed for the satellite tracking using the application Matlab with input from the NORAD Two-Line Element Set Format.

## 2. SATELLITE TRACKING WORKFLOW

In order to complete the task of developing one application for satellite tracking for common use, a series of objectives are defined:

- user-friendly interface of the application;
- easy access for satellite data;
- graphical display of all performed operations;
- graphical display of complete satellite data;
- complete separation of input and output data;
- tables for conclusions regarding satellite orbit;

The steps taken for the development of the desired application corroborated with the completion of the objectives presented beforehand are:

- a) reading of the NORAD Two-Line Element Set Format for the chosen satellite;
- b) extraction of necessary information such as: satellite name, eccentricity, inclination, argument of periapsis, mean anomaly, longitude of the ascending node and mean motion;
- c) mathematical calculations of necessary input for the application;
- d) starting point determination, all points of the satellite track being characterized by vector radius and vector speed;
- e) differential calculus in order to obtain the satellite's orbit;
- f) projection of satellite's orbit onto Earth's surface, without and with revolution movement;
- g) mathematical determination of the satellite's rate of decay;
- h) graphical display in Earth's atmosphere for the last two steps;

Thus, the required information for the application to function and perform the desired operations are the NORAD Two-Line Element Set Format and the mathematical model for satellite orbits.

## 3. NORAD Two-Line Element Set Format

Firstly, the NORAD Two-Line Element Set Format is a data format used to transmit one coded set of orbital elements that perfectly describe the satellite's orbit around Earth. An application could use this set in order to compute the exact position at any moment of the tracked satellite. This TLE format is a specific one used by NORAD and NASA. Also, these formats are distributed freely around the world by means of the Internet and contain three lines: one title line and two lines of coded text.

For a better understanding of the NORAD Two-Line Element Set Format coding, a visual description using the International Space Station TLE is performed:

```
ISS (ZARYA)
1 25544U 98067A 04236.56031392 .00020137 00000-0 16538-3 0 9993
2 25544 51.6335 344.7760 0007976 126.2523 325.9359 15.70406856328903
-----
123456789012345678901234567890123456789012345678901234567890 reference number line
1 2 3 4 5 6 7
```

FIG. 1. International Space Station TLE [4]

Table 1. International Space Station TLE – description [4]

| Line 0  |                |   |
|---------|----------------|---|
| Columns | Example        | Description   |
| 1-24    | ISS (ZARYA)    | Object common name based on information from the Satellite Catalog.               |
| Line 1  |                |   |
| Columns | Example        | Description   |
| 1       | 1              | Line Number   |
| 3-7     | 25544          | Satellite Catalog Number  |
| 8       | U              | Elset Classification  |
| 10-17   | 98067A         | International Designator  |
| 19-32   | 04236.56031392 | Element Set Epoch (UTC)<br>*Note: spaces are acceptable in columns 21 & 22        |
| 34-43   | .00020137      | 1st Derivative of the Mean Motion with respect to Time                            |
| 45-52   | 00000-0        | 2nd Derivative of the Mean Motion with respect to Time<br>(decimal point assumed) |
| 54-61   | 16538-3        | B* Drag Term  |
| 63      | 0              | Element Set Type  |
| 65-68   | 999            | Element Number  |
| 69      | 3              | Checksum  |
| Line 2  |                |   |
| Columns | Example        | Description   |
| 1       | 2              | Line Number   |
| 3-7     | 25544          | Satellite Catalog Number  |
| 9-16    | 51.6335        | Orbit Inclination (degrees)   |
| 18-25   | 344.7760       | Right Ascension of Ascending Node (degrees)                                       |
| 27-33   | 0007976        | Eccentricity (decimal point assumed)  |
| 35-42   | 126.2523       | Argument of Perigee (degrees)   |
| 44-51   | 325.9359       | Mean Anomaly (degrees)  |
| 53-63   | 15.70406856    | Mean Motion (revolutions/day)   |
| 64-68   | 32890          | Revolution Number at Epoch  |
| 69      | 3              | Checksum  |

From fig. 1 and table 1 presented above, it can be clearly seen that the line of interest for the desired application is line 2, especially columns 9 to 63. Based on the data coded in this line – which are actually the orbital elements of the satellite’s orbit – a complete tracking of the satellite can be performed. Adding the mathematical model of the application, the user-friendly interface and the graphical display of all satellite data, the objectives of the desired application will be achieved.

#### 4. ORBITAL ELEMENTS

Orbital elements are the parameters required to identify in a unique manner the orbit of a specific satellite. In space mechanics, these orbital elements are generally considered in classical two-body systems. These systems are using the classical Keplerian orbit description which is derived from Newton's laws of motion and Newton's law of universal gravitation. Many different way to describe the same orbit from a mathematical point of view exist, but certain schemes – which have become more popular due to their simple way of use – each consisting of a set of six parameters, are commonly used in orbital mechanics.

The Keplerian orbit is just an idealization, a mathematical approximation at a particular time, while a real orbit (and its elements) change over time due to perturbations by other objects – gravity of those object as an example – and the effects of relativity.

Five independent quantities entitled orbital elements are sufficient to completely describe the size, shape and orientation of an orbit. In fig. 2 the classical set of orbital elements are shown:

- $a$  – semi-major axis; this element defines the size of the orbit;
- $e$  – eccentricity; this element gives the shape of the orbit;
- $i$  – inclination; this element represents the orientation of the orbit with respect to Earth's equator;
- $\omega$  – argument of periapsis; this element defines where the low point, called perigee, of the orbit is with respect to the Earth's surface;
- $\Omega$  – longitude of the ascending node; this element represents the location of the ascending and descending orbit locations with respect to the Earth's equatorial plane;
- $v_o$  – true anomaly at epoch; this element notes where the satellite is within the orbit with respect to the perigee;
- $t_o$  – time at epoch;
- $T$  – time at periapsis passage;
- $\Pi$  – longitude at periapsis;

$$\Pi = \varpi + \Omega \quad (1)$$

- $u_o$  – argument of latitude at epoch;

$$u_o = \varpi + v_o \quad (2)$$

- $l_o$  – true longitude at epoch;

$$l_o = \Omega + \varpi + v_o = \Pi + v_o = \Omega + u_o \quad (3)$$

- $p$  – semi-latus rectum;



Alongside this orbital elements, three fundamental vector are also required:

a) angular momentum,  $\vec{h}$ ; it is the vector normal to the orbital plane

$$\vec{h} = \vec{r} \times \vec{v} = \begin{bmatrix} \vec{I} & \vec{J} & \vec{K} \\ r_x & r_y & r_z \\ v_x & v_y & v_z \end{bmatrix} = h_x \cdot \vec{I} + h_y \cdot \vec{J} + h_z \cdot \vec{K} \quad (4)$$

b) node vector,  $\vec{n}$ ; it is the vector pointing along the line of nodes in the direction of the ascending node;

$$\vec{n} = \vec{K} \times \vec{h} = \begin{bmatrix} \vec{I} & \vec{J} & \vec{K} \\ 0 & 0 & 1 \\ h_x & h_y & h_z \end{bmatrix} = n_x \cdot \vec{I} + n_y \cdot \vec{J} + n_z \cdot \vec{K} = -h_y \cdot \vec{I} + h_x \cdot \vec{J} \quad (5)$$

c) eccentricity vector,  $\vec{e}$ ; it is the vector which points from the center of the earth (focus of the orbit) towards the perigee with a magnitude exactly equal to the eccentricity of the orbit;

$$\vec{e} = \frac{1}{\mu} \cdot \left[ \left( v^2 - \frac{\mu}{r} \right) \cdot \vec{r} - (\vec{r} \cdot \vec{v}) \cdot \vec{v} \right] \quad (6)$$

## 5. MATHEMATICAL MODEL OF APPLICATION

With all these elements in place, the problem of determining the vector for radius and speed of the satellite, when the orbital elements are known, can be solved. Assuming the following orbital elements are given:  $p$ ,  $e$ ,  $i$ ,  $\Omega$ ,  $\omega$  and  $\nu$ , the radius vector can be written in the perifocal system [6]:

$$\vec{r} = r \cos \nu \vec{P} + r \sin \nu \vec{Q} \quad (7)$$

where:

$$r = \frac{p}{1 + e \cos \nu} \quad (8)$$

Thus, considering equation (7), the speed vector can be written in the perifocal system as:

$$\vec{v} = \frac{d\vec{r}}{dt} = \sqrt{\frac{\mu}{p}} \left[ -\sin \nu \vec{P} + (e + \cos \nu) \vec{Q} \right] \quad (9)$$

The transformation between perifocal system and geocentric system is needed:

$$\begin{bmatrix} a_I \\ a_J \\ a_K \end{bmatrix} = \tilde{R} \begin{bmatrix} a_P \\ a_Q \\ a_W \end{bmatrix} \Leftrightarrow \vec{a}_{IJK} = \tilde{R} \vec{a}_{PQW} \quad (10)$$

where:

$$\tilde{R} = \begin{bmatrix} \cos \Omega \cos \varpi - \sin \Omega \sin \varpi \cos i & -\cos \Omega \sin \varpi - \sin \Omega \cos \varpi \cos i & \sin \Omega \sin i \\ \sin \Omega \cos \varpi + \cos \Omega \sin \varpi \cos i & -\sin \Omega \sin \varpi + \cos \Omega \cos \varpi \cos i & -\cos \Omega \sin i \\ \sin \varpi \sin i & \cos \varpi \sin i & \cos i \end{bmatrix} \quad (11)$$

The mathematical model is established, the NORAD Two-Line Element Set Format coding is explained and the application presentation follows in the next chapter.

## 6. APPLICATION PRESENTATION

Incorporating all of the above into the Matlab application [7], the results for the data mentioned in fig. 1 are shown below:

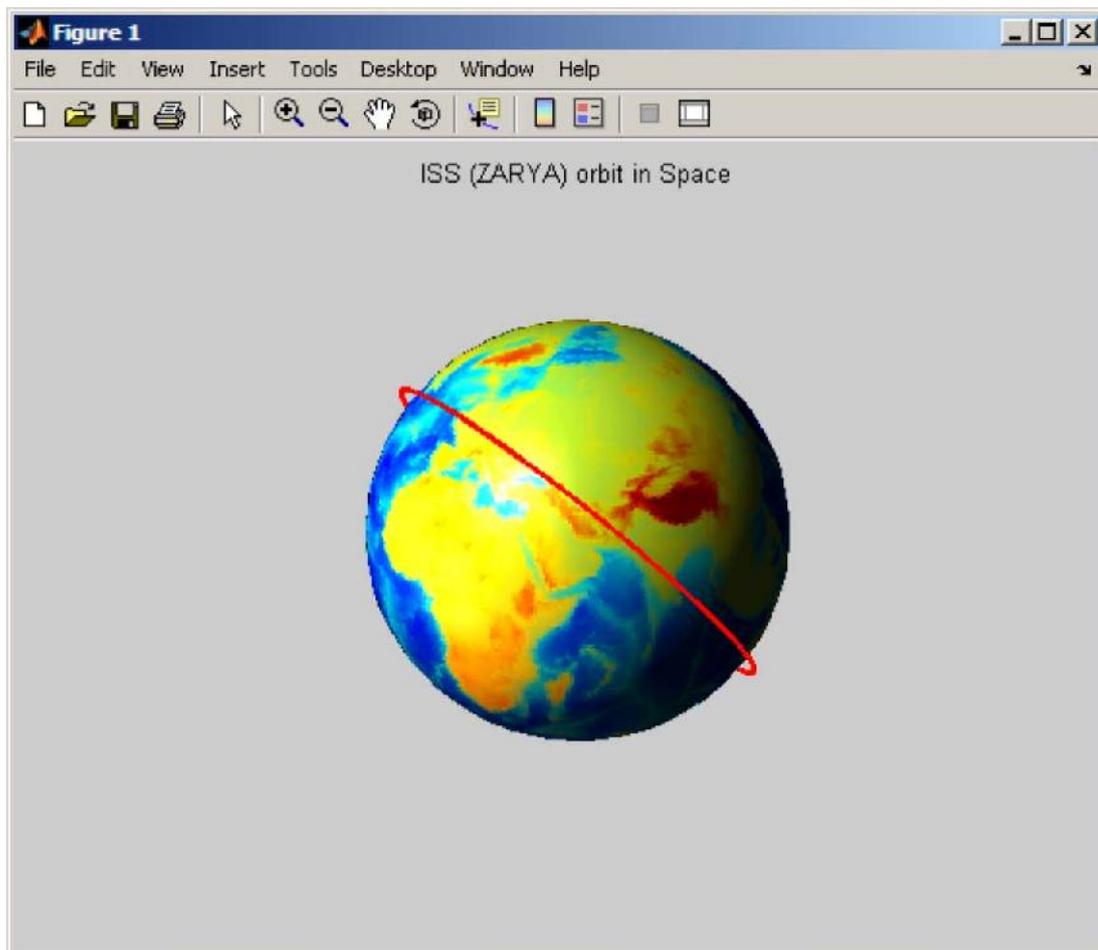
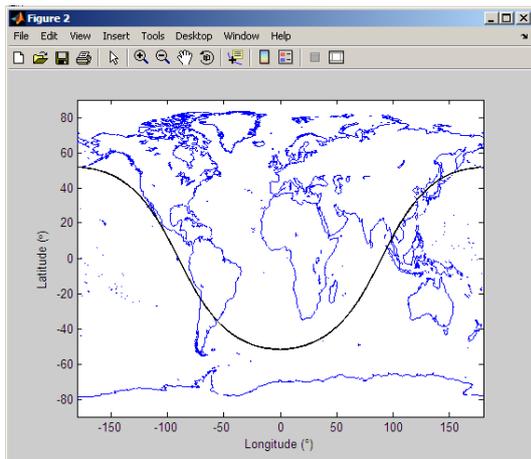
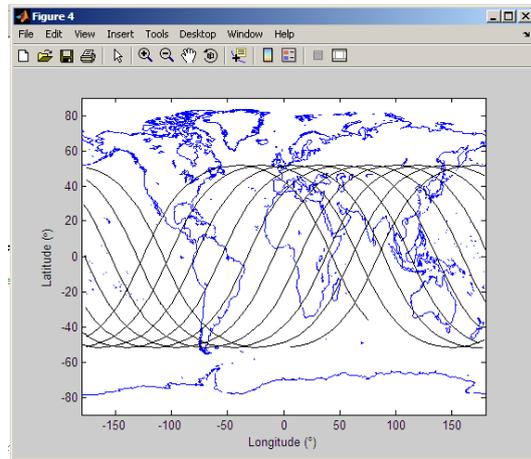


FIG. 3. International Space Station Orbit

The next step is given by performing the projection of the satellite's orbit on the Earth's surface, at first without considering the rotation of the Earth (fig. 4a) and after with this consideration (fig. 4b), and the calculation and display of the rate of decay of the same satellite (fig. 5).

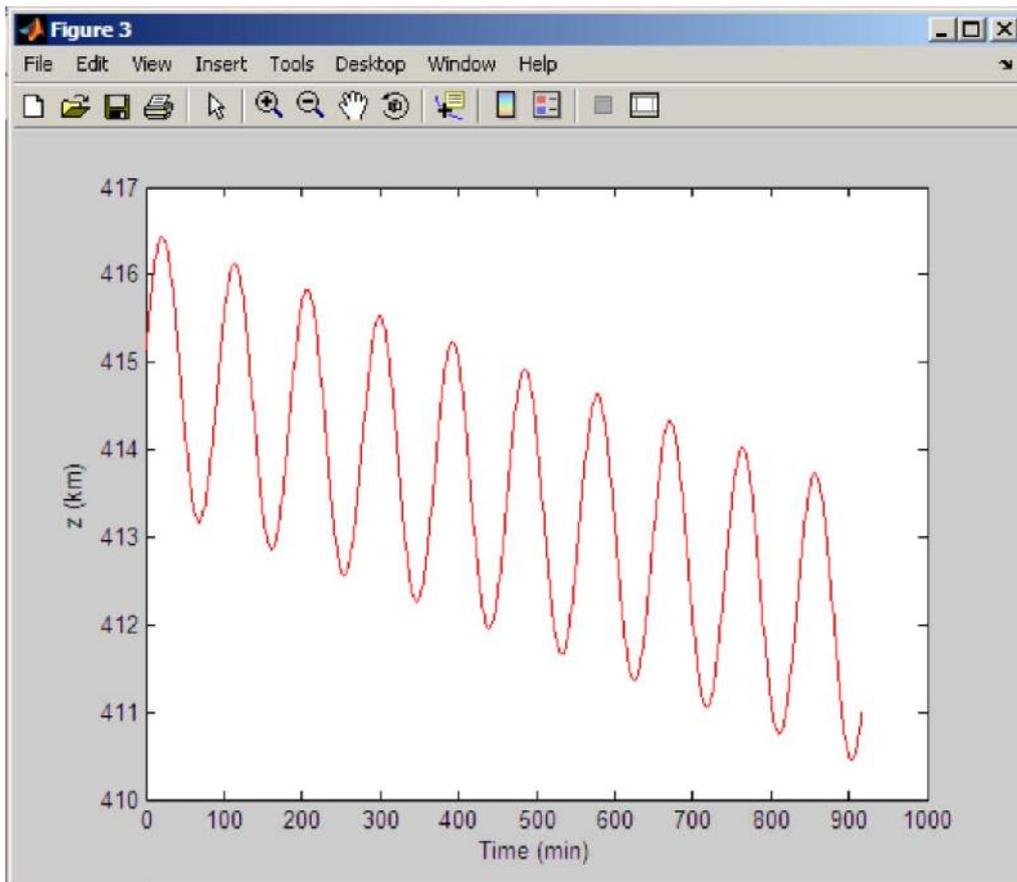


(a)



(b)

**FIG. 4.** International Space Station Orbit Projection on Earth's Surface:  
a – without Earth's rotation; b- with Earth's rotation



**FIG. 5.** International Space Station Rate of Decay

## CONCLUSIONS

One can imagine that in order to track the increasing number of satellites and space debris objects, the human and computational effort is very high without a specialized, and at the same time simple, application like the one presented by this paper. And although awareness regarding this subject is on the rise thru different state or private funded programs [8], more solutions are needed in order to have a clean sky to look upon at night.

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