

User Guide for Satellite Design GUIs

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1 Overview

1.1 Audience and Goals of GUIs

These satellite design GUIs were developed as a teaching tool to aid a student taking an introductory spacecraft engineering course. These GUIs will be best understood by a user with knowledge of dynamics, linear algebra, and calculus. These GUIs provide an interactive demonstration of a few basic satellite design concepts.

1.2 System Requirements

These GUIs are compatible with MATLAB version 16a or later. All GUIs except the Sun Synchronous GUI require MATLAB's mapping toolbox to be installed.

2 Sun Synchronous Orbit Design GUI

2.1 GUI Overview

2.1.1 Goals of GUI

This GUI is designed to demonstrate a sun synchronous orbit for a satellite orbiting a planet. A sun synchronous orbit means that the satellite passes over any given point of the planet's surface at the same local solar time. The user may select any planet in the solar system for the satellite to orbit around.

The GUI has two modes, auto and manual. In auto mode, if the user changes an input field, the other inputs of the orbit will change to make the orbit sun synchronous. The user will always see a sun synchronous orbit. In manual mode, the GUI does not automatically change any inputs. The user can make any orbit, it does not have to be sun synchronous.

2.1.2 Important Equations and concepts

For an orbit to be sun synchronous, the change in right ascension of the ascending node, RAAN, will match the rotational speed of the planet orbiting the sun.

The angular precession of an orbit is caused by the oblateness of a planet.

$$\Delta\Omega = \frac{3}{2} * (1 - e^2)^2 * n * J_2 * \left(\frac{R}{a}\right)^2 * \cos(i) \quad (1)$$

where:

$\Delta\Omega$ = change in RAAN of orbit

e = eccentricity of orbit

n = mean motion of orbit

J_2 = oblateness of planet

R = radius of planet

a = semi major axis of orbit

i = inclination of planet

For equations that describe the orbit and position of the satellite, see Section 3.1.2.

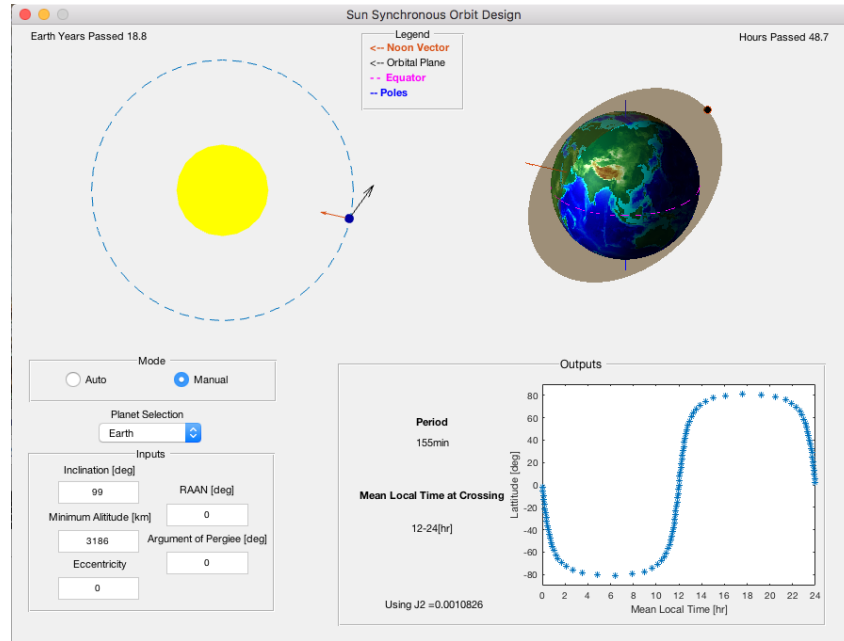


Figure 1: The Sun Synchronous GUI

2.2 Visual Guide of Interface

2.2.1 Solar Axis

The upper left axis on the GUI depicts the planet's rotation around the Sun. The time passed since the start of animation is printed in the top left. Note that this time does not match that of the right axis. The solar axis animates on a yearly scale, where the planet axis animates on the scale of days. The orange vector on the planet depicts the noon vector, or the vector that originates at the planet's center and points in the direction of the Sun at all time. This vector depicts the position of solar noon on the planet. The black vector on the planet depicts the orbital vector. This vector lies along the plane of the orbit. For a sun synchronous orbit, the angle between the orbital vector and the noon vector does not change.

2.2.2 Planet Axis

The upper right axis on the GUI depicts a closer view of the satellite's rotation about the planet. The orbital plane is shaded in. There is a noon vector which points from the center of the planet towards the Sun. The planet rotates about its poles. A line through the poles is shown in blue. The equator is shown as a pink dashed line on the surface of the planet. The Earth time passed since the start of animation is displayed in the top right. Note that this time does not match that on the left axis. The solar axis animates on a yearly scale, where the planet axis animates on the scale of days.

2.2.3 Inputs

The user can select which planet the satellite orbits from the drop down menu. The user can also change the orbital elements. The inclination of the orbit, RAAN, and argument of perigee are alterable and in degrees. See 2 for a diagram of these angles. The minimum altitude of the orbit is an input in kilometers. The term minimum is used in case there is eccentricity. Eccentricity is an input and is meant to be between 0 and 1. If there are issues with any of these orbital elements, an error will be displayed below the inputs box.

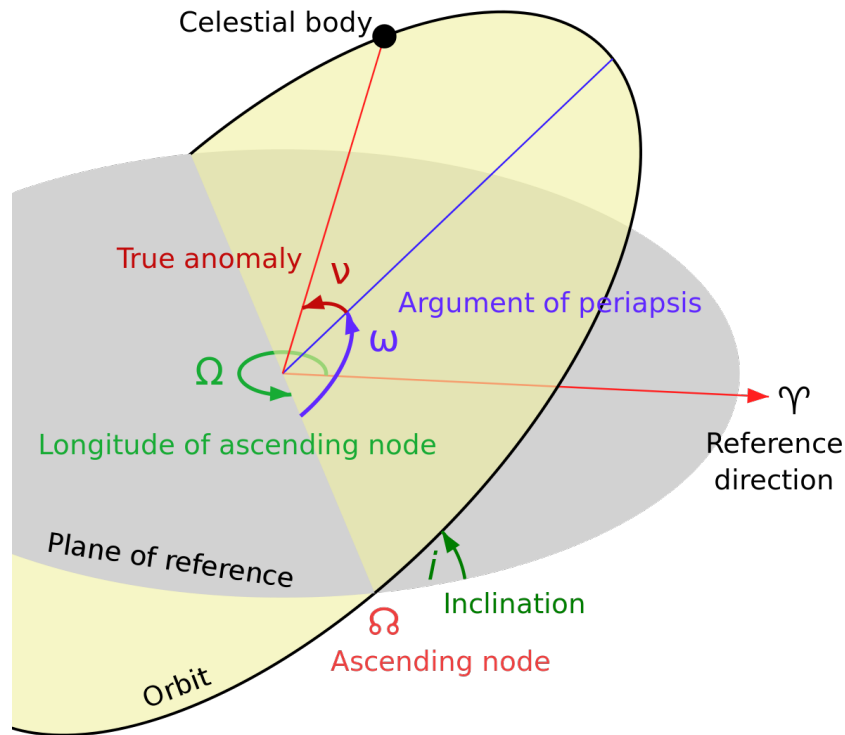


Figure 2: A diagram of the orbital angles. Source: https://en.wikipedia.org/wiki/Orbital_inclination

2.2.4 Outputs

The period of the orbit is displayed. The mean local time of crossing displays the local solar time at the equatorial crossing of the orbit. The J2, or oblateness value, of each planet is displayed. Sun synchronous orbits are only possible on oblate planets. The latitude as a function of the mean local time for a few periods of the satellite's orbit is displayed. A sun synchronous orbit will pass over the same spot at the same local time every period.

2.3 Using Manual Mode

The user can change any of the inputs and see the resultant orbit. The goal of this mode is to have the user try to create a sun synchronous orbit. The user can see when they have created a sun synchronous orbit as the angle between the orbital plane vector and the noon vector on the solar axis will not change. Also the output graph will show that the satellite will always pass over a point on the planet at the same local time.

2.4 Using Auto Mode

If the user changes inclination, altitude, or eccentricity to a valid input, the orbital elements will update themselves to keep the orbit sun synchronous.

Upon selection of a planet, if the planet is not oblate enough to support a sun synchronous satellite orbit, an error will display in the output box.

3 Satellite Ground track GUI

3.1 GUI Overview

3.1.1 Goals of GUI

This GUI depicts the orbit of an Earth-based satellite, including the ground track and swath of the satellite's orbit. This GUI can be used to develop an understanding of the orbital elements and how they impact the satellite's ground track on the Earth.

3.1.2 Important Equations and concepts

These equations come from *Space Mission Engineering: The New SMAD*. See Figure 2 for a diagram of orbital angles.

Satellite Mean Motion

$$n = \sqrt{\frac{\mu}{a^3}} \quad (2)$$

a = semi major axis of orbit

μ = gravitational parameter of Earth

Satellite Mean Anomaly

$$M = M_0 + nt \quad (3)$$

M_0 = initial mean anomaly

t = time

Satellite True Anomaly

Using the first term of the power series as an approximation:

$$v \approx M + (2e - \frac{e^3}{4} + \frac{e^5}{96})\sin(M); \quad (4)$$

Satellite Radius

$$r = \frac{a(1 - e^2)}{1 + e\cos(v)}; \quad (5)$$

e = eccentricity of orbit

v = true anomaly of orbit

Satellite Velocity

$$v = \sqrt{\mu(\frac{2}{r} - \frac{1}{a})}; \quad (6)$$

Satellite Position in ECEF

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} r * \cos(\Omega) \cos(\omega + v) - r * \sin(\Omega) \sin(\omega + v) \cos(i) \\ r * \sin(\Omega) \cos(\omega + v) + r * \cos(\Omega) \sin(\omega + v) \cos(i) \\ r * \sin(\omega + v) \sin(i) \end{bmatrix} \quad (7)$$

3.2 Visual Guide of Interface

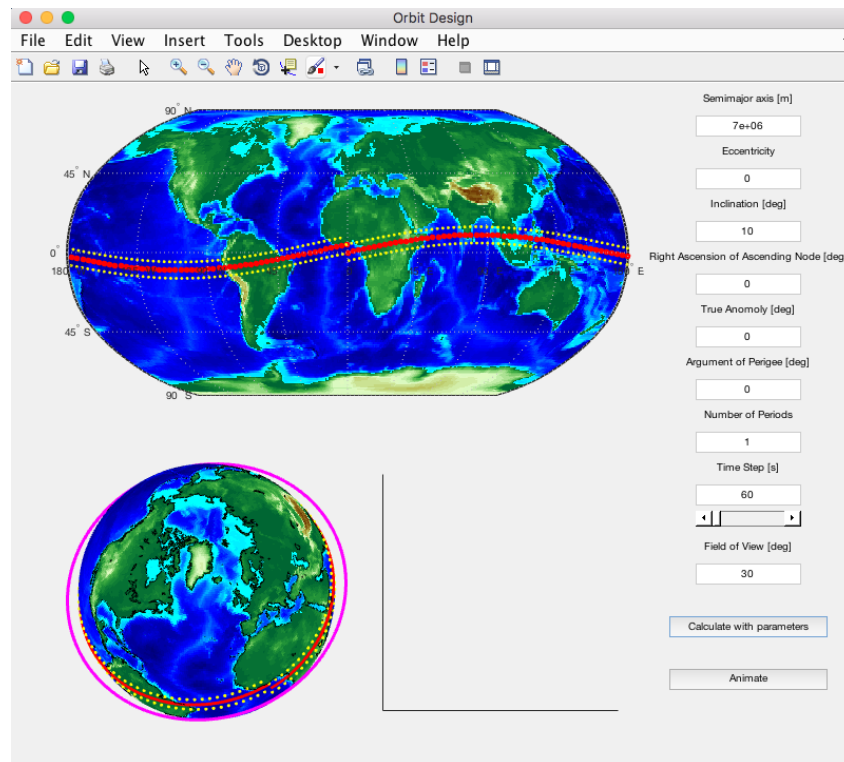


Figure 3: Satellite Ground track GUI after pressing the Calculate button.

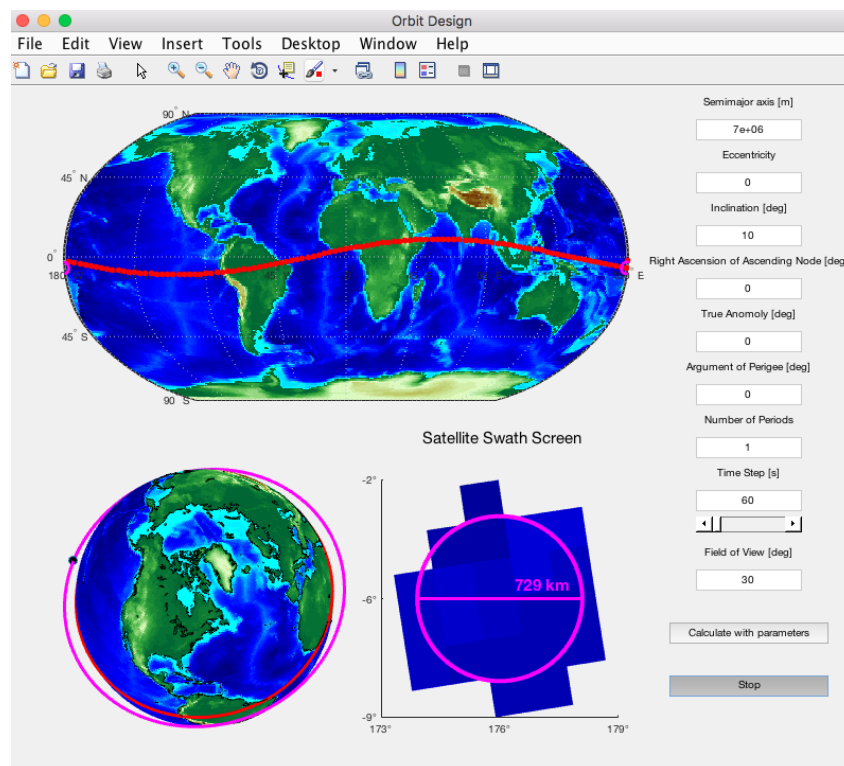


Figure 4: Satellite Ground track GUI after pressing the Animate button.

3.3 Inputs

The six orbital elements can be input by the user. These are:

- Semi major axis of the orbit (a) in meters
- Eccentricity (e) which should be $0 \leq e \leq 1$
- Inclination (i) in degrees
- RAAN (Ω) in degrees
- True Anomaly (v) in degrees
- Argument of Perigee (ω) in degrees

For a diagram of the orbital angles, see Figure 2.

There are also a few variables related to how the orbit is represented in this GUI. The user can select:

- The number of periods depicted.
- The time step of the animation. This controls the speed of the animation. The larger the time step, the faster the animation.
- The field of view in degrees. This controls the size of the swath of the satellite. For a diagram of this angle, see the legend in Figure 7.

3.4 Using the Calculate Button

After pressing the calculate button, the GUI will display a static representation of the path of the satellite. The red line on the surface of the Earth represents the spot directly underneath the satellite, or the ground track. The yellow dotted lines outline the edges of the swath on Earth's surface. This is the area within the field of view of the satellite. The pink orbit depicted on the globe view of the Earth is the satellite's orbit in space.

3.5 Using the Animate Button

The animate button provides a depiction of the satellite swath in the bottom right axis. This is a representation of what the satellite sees as it orbits. The swath is represented as a circular field of view. Note that the resolution of the swath is limited by the pixel size of the map used in this GUI. The resolution of the swath has no relation to the resolution of the satellite's sensor.

During animation, when the user changes the inputs and would like to see the updated orbit, the user must stop animation using the stop button and restart the animation using the animate button.

The time step allows the user to control the speed of the animation. A larger time step corresponds to a faster animation.

4 Remote Sensing GUI

4.1 GUI Overview

4.1.1 Goals of GUI

This GUI depicts in detail an Earth observing satellite. The user may choose either a pushbroom or whiskbroom sensor for the satellite. Then the user may specify parameters of the satellite orbit and sensor. The user will then see an animation of the sensor's motion and field of view as the satellite orbits.

4.1.2 Important Equations and concepts

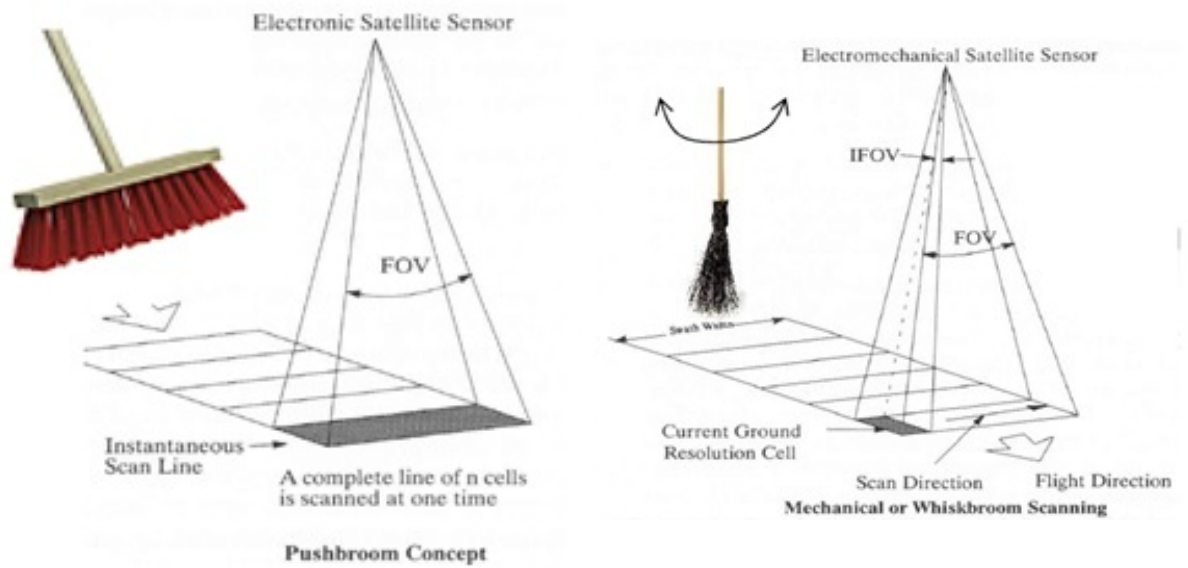


Figure 5: The difference between pushbroom and whiskbroom sensors. Source: http://www.tankonyvtar.hu/en/tartalom/tamop425/0032_terinformatika/ch05.html

Ground Velocity

$$V_g = \frac{R_e}{R_e + h} * V \quad (8)$$

R_e = radius of the Earth

h = height above Earth's surface

v = orbital velocity of satellite

Diffraction Limited Resolution

$$\Delta x' = \frac{1.22h\lambda}{D} \quad (9)$$

λ = wavelength of sensor

D = diameter of aperture

Ground Spatial Resolution

$$\Delta x = \frac{hp}{f} \quad (10)$$

p = pixel size

f = focal length of aperture

Integration Time

Pushbroom

$$\tau = \frac{\Delta x}{V_g} \quad (11)$$

Whiskbroom

$$\tau = \frac{N_y \Delta x}{2 N_x V_g} \quad (12)$$

N_y = number of pixels in along track direction.

N_x = number of pixels in cross track direction.

Swath

Pushbroom

$$2h * \tan\left(\frac{N_x IFOV}{2}\right) \quad (13)$$

Whiskbroom

$$2h * \tan\left(\frac{FOR}{2}\right) \quad (14)$$

For a diagram of FOR, field of regard, and IFOV, instantaneous field of view, please see Figure 7.

Data Rate

Pushbroom

$$\frac{N_x N_{band} \frac{\#bits}{pixel}}{\Delta x / V_g} \quad (15)$$

Whiskbroom

$$\frac{N_x N_y N_{band} \frac{\#bits}{pixel}}{\Delta x / V_g} \quad (16)$$

4.2 Visual Guide of Interface

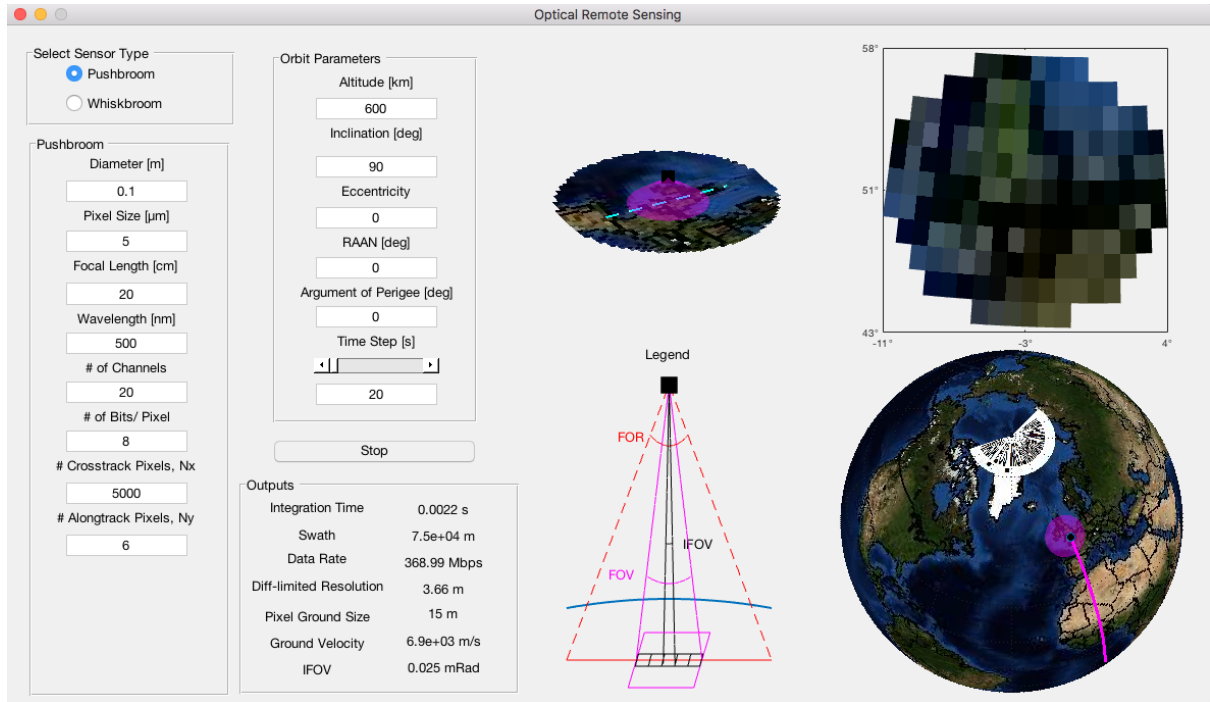


Figure 6: Remote Sensing GUI displaying a pushbroom sensor.

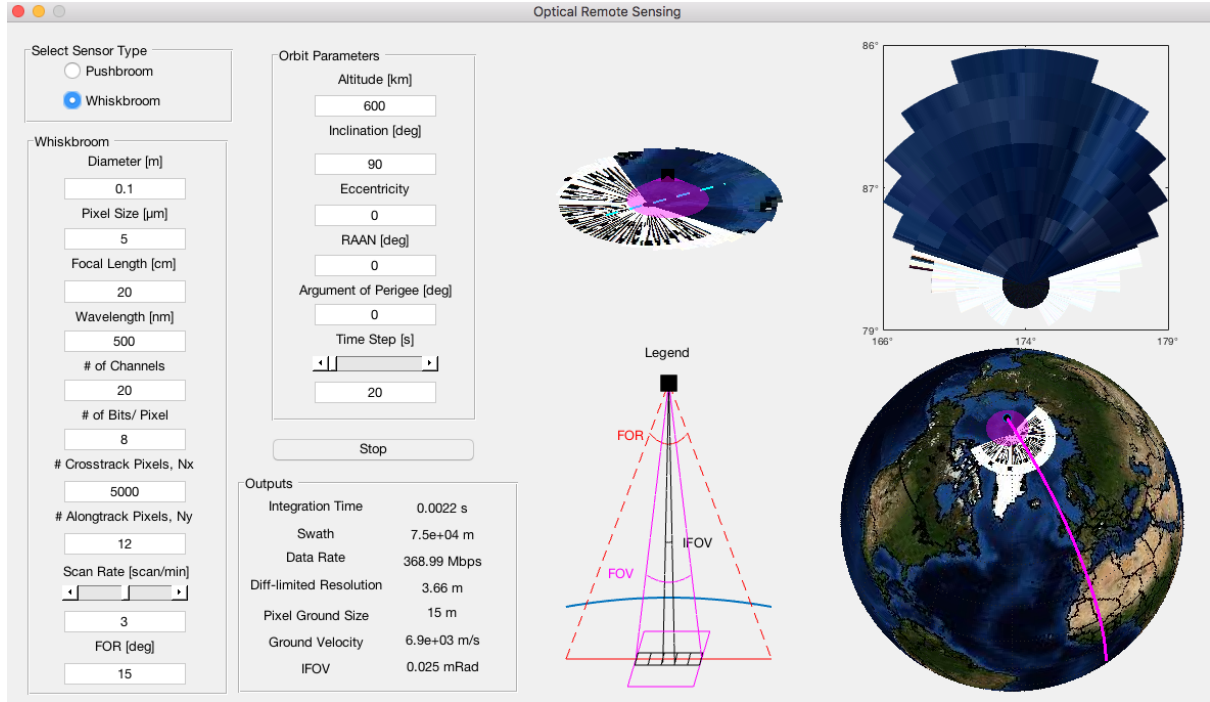


Figure 7: Remote Sensing GUI displaying a whiskbroom sensor.

4.3 Using the GUI

4.3.1 Inputs

The orbital elements can be changed by the user. For details on these elements, see Section 3.1.2. The rest of the inputs are:

- Diameter of the aperture (D) in meters
- Pixel size (p) of the image in micrometers
- Focal Length (f) of the aperture in centimeters
- Wavelength of light (λ) used by sensor
- Number of channels (N_{band})
- Number of cross track pixels (N_x) in the field of regard (FOR)
- Number of along track pixels (N_y) in the field of regard (FOR)
- Scan rate describes the speed at which the scanner moves, or the speed at which the FOV swings through the FOR.

4.3.2 Legend

FOR stands for field of regard. FOR is the total area that can be captured by a moveable sensor.

FOV stands for field of View. FOV is what can be seen at any one time by the sensor.

IFOV stands for instantaneous field of view. Assuming the sensor can pick up one pixel at a time, the IFOV describes a single pixel.

4.3.3 Swath View

The axis in the upper right of the GUI depicts the image the satellite sees in its FOV. The latitude and longitude of the images are shown. The satellite is above the part of the Earth shown. Note that the resolution of this view depends upon the resolution of the GUI's map, which is limited. The displayed resolution does not correlate to the satellite's calculated resolution.

4.3.4 Close Up Satellite View

The upper left view depicts a view of the satellite going over the surface of the Earth. The blue dotted line beneath the satellite depicts the ground track, or path of the satellite on the surface of the Earth. The pink cone is a depiction of the field of view of the sensor on the satellite. Depending on which sensor is selected, the user can see the field of view move in the along track (pushbroom) or cross track (whiskbroom) direction.

4.3.5 Globe View

This bottom right view of the satellite shows the satellite orbiting the Earth.

4.3.6 Outputs

- Integration time is the dwell time for a single pixel in seconds.
- Swath is the distance in meters of the FOR.
- Data rate in megabits per second is required by the sensor to send its images.
- Diffraction limited resolution is the smallest size of a pixel in meters on the Earth that the sensor could have.
- Pixel ground size is measured in meters on the surface of the Earth
- Ground velocity is the satellite's velocity with respect to a point on the Earth's surface.
- IFOV is the instantaneous field of view in milliradians.

4.4 Using the GUI

If the user would like to change the inputs during animation, the user must hit the stop/animate button twice. The animation must be stopped and restarted to see an updated animation if an input changes.

Note that all graphs on the GUI can be rotated and seen from any angle.