BACHELOR’S DEGREE THESIS IN AEROSPACE VEHICLES ENGINEERING

Study of the interlink between small satellites in a constellation

SOFTWARE USER GUIDE

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1. Introduction

The thesis “Study of the interlink between small satellites in a constellation” led to the development of the Interlink code, a tool to quickly determine visibility windows between satellites in a constellation. The code was developed in Matlab R2017b.

As a quick recap, these are the main features offered:

- Multiple satellites input
- Celestial system election
- Custom simulation period parameters
- Orbit tracking using SGP4 perturbations model
- Visibility prediction for all satellite pairs combinations
- Pathfinding for optimized data transfers between satellites
- Plots and animations
- Logging, for a simulation history

It also resulted in the creation of an interactive dashboard used as an effective analysis instrument, taking advantage of the CSV data insertion implemented in Interlink code. This part was developed using Power BI.

1.1 Getting started

The following figure shows the folders’ structure system.

![Folders structure diagram](image)

Figure 1.1: Folders’ structure

The main program is Interlink. Every time a simulation runs, the log file goes into logs folder and all data is inserted in a CSV file - automatically created if it does not exist - that goes into Data Output Files. Into this last mentioned folder, it also goes the animation in case of Live Plot option is selected.
CHAPTER 1. INTRODUCTION

*Plot Earth* contains the necessary functions responsible for generating the 3D Earth environment in which orbits will be plotted. *SGP4* folder contains the function for the orbit propagation. *TLE plotter* contains the functions needed to compute the position in Earth-centered inertial frame. It also provides a Newton-Raphson iteration method, and part of the code in which the *Static plot* and TLE input methods are based.

Lastly, *TLE input files* is just a folder to store TXT files that can be used as an input for the *Interlink* code.

All paths are set automatically, the user does not have to change them in order to have all output files going to the right place.

1.2 Contributors

*Interlink* makes use of functions developed by other contributors. They are stored in the following separate folders:

- *Plot Earth* functions were developed by Bruno Luong. [1]
- *SGP4* function was developed by Meysam Mahooti. [2]
- *TLE plotter* was developed by Tyler G. R. Reid. [3]
2. How to use Interlink code

Open Matlab and then open Interlink.m file. Press run button to start.

2.1 Cover

This is an informative cover regarding the authors.

![Figure 2.1: Cover window](image)

2.2 Celestial Object System module

This window enables to choose if the user wants to get the constants for Earth (default option) or for another celestial body. Take into account that the last option would require two-line elements (TLE) adapted for the expected celestial object.

![Figure 2.2: Celestial object system window](image)
If the user selects *Other*, it pops up the following constants’ definition in the units expected.

![Figure 2.3: Setting celestial object’s constants](image)

### 2.3 TLE input module

This module enables the introduction of satellites in the analysis. The minimum required is always two. Let’s take a look at the options.

![Figure 2.4: TLE input window](image)

First option allows using some hard-coded examples. User can select two or more satellites to run the program.

![Figure 2.5: Examples’ selection window](image)
The second option pops up a file management window that lets the user to choose a TXT file - from any path in your computer - with all the satellites defined in TLE and arranged using the following format.

![Figure 2.6: TXT file format](image)

The third option allows pasting TLE as it sometimes may be the most convenient input for a quick analysis. When this option is selected, it appears a window where the user has to set the number of TLE that is about to input.

![Figure 2.7: Number of TLE to paste](image)

Then, it is time to paste, following the format expressed in 2.6.

![Figure 2.8: Paste TLE window](image)

### 2.4 Simulation time module

This module is meant to establish the time period and the time divisions for the upcoming analysis. Default option sets the analysis start at the time of selection and the end 24 hours later. It also sets a 500 time divisions. In some cases, where visibility periods are short, 500 time divisions is too low. That is the reason why Other option is implemented.
CHAPTER 2. HOW TO USE INTERLINK CODE

Figure 2.9: Simulation time window

*Other* option enables to select a custom start, time and number of time divisions. Use the datetime format specified in the example shown in the window.

Figure 2.10: Custom simulation time window

### 2.5 Logging module

This module sets the name for the log file that the analysis will create and send to *logs* folder. The expected format is shown in the window, it is the processing time and the name set by the user. It is useful for a quick identification of simulations in history.

Figure 2.11: Log file window

### 2.6 Plot module

This module allows the selection of the kind of visualization desired. *Static Plot* is a figure with the whole orbit traced during the simulation. Earth is showing the position at simulation start. *Live Plot*, on the other hand, shows the orbit trace live, for each pair of satellites and for each step in the simulation time. It also opens the *Static Plot* figure and plots the animated orbit tracing on top. It creates an MP4 animation and sends it to *Data Output Files*. 
Warnings for *Live Plot*:

- Take into account that this can take a long time.
- Do not maximize, or re-size the Live Plot while recording.

![Plot window](image)

**Figure 2.12: Plot window**

*Static Plot* generates a random color for each satellite and prints the starting point with a marker.

![Static Plot](image)

**Figure 2.13: Static Plot**

*Live Plot* shows green orbit traces when there is direct line of sight and red orbit traces when non-visibility happens between the pair of satellites analyzed. Once it finishes the first pair, it starts plotting the second one, and like this until the last pair of satellites. The Earth is not rotating in this plot, it does not affect the visibility result. However, the Earth would rotate so it is not meant to track sub-satellite points.
2.7 Pathfinding module

This module allows to calculate the quickest path between two satellites for a data transfer during the simulation. It requires to choose the receiver and sender among the satellites given as input. It also requires the duration for the data transfer. This is meant to simulate sending, encoding, modulation, demodulation, decoding and storing processes.

(a) Satellite sender

(b) Satellite receiver

Figure 2.15: Pathfinder definition

Figure 2.16: Transfer data duration
3. How to use Interlink dashboard

All the data given by the calculations during the analysis is stored in a CSV file. This structured data can then be given as input for a data analytics tool. In this case, Power BI.

Remember to change all settings to English (United States) to get the numbers in the correct format (commas placed correctly). You can always open the file with the notepad to see the actual data generated.

Users can bring data to Power BI by pressing Get Data button and selecting CSV option or by changing the source in Edit Queries, taking advantage of the necessary calculated columns already implemented to show time filters.

The following figure shows the dashboard created. On the left, the filters where users can set which pair of satellites has to be analyzed and the period by day and by hour. In the middle the plots showing the visibility and the margin visibility. Lastly, on the right side a table with all the raw data.

![Power BI dashboard](image)

Figure 3.1: Power BI dashboard
Bibliography

