Cairo University

SPACECRAFT ORBIT ESTIMATION VIA OPTICAL OBSERVATION

by

Eng. Karim Ahmed Abdelrazik Hassan Kamalaldin

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfilment of the
Requirements for the Degree of
MASTER OF SCIENCE
In
AEROSPACE ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNVERSITY
GIZA, EGYPT.
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Title of Thesis:

SPACECRAFT ORBIT ESTIMATION VIA OPTICAL OBSERVATION

Key Words:

Orbit Estimation; Optical observation; Satellite Tracking; ISS Tracking; Satellite Imaging.

Summary:

This thesis presents a methodology in how to correct the knowledge about the satellite's position and velocity, using azimuth and elevation measurements. Azimuth and elevation measurements mean optical observation measurements. Comparing the propagated values with the measured values at the measuring time, and try to find the best satellite initial condition (position and velocity) which produce minimum difference between the propagated and measured values. This process is used to correct the information about the satellites initial condition. The corrected satellite initial condition is used for propagation for further period of time. Using low cost commercial camera to get our measurements, where these measurements are the satellite azimuth and elevation angles with respect to the observer topo-centric axis. Images for the sky were taken while the satellite is passing above the observation site. Satellite's azimuth and elevation angles can be obtained from these images. These azimuth and elevation measurements could be used to correct the satellite initial condition. The minimum required number of measurements and it is corresponding accuracy could be obtained in order to correct the satellite initial condition.

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Karim Kamalaldin.

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Nomenclature

ISS	International Space Station
NWZ	North-West-Zenith System of Axes
β	Satellite's Azimuth angle
el	Satellite's elevation angle
CCD	Charge Coupled Device
Φ_c	Camera azimuth angle with respect to Topo-centric axes.
λ_c	Camera elevation angle with respect to Topo-centric axes.
Φ_1	First star azimuth angle with respect to Topo-centric axes.
λ_1	First star elevation angle with respect to Topo-centric axes
NWZ	North West Zenith system of axes.
V_1	First star unit vector with respect to NWZ axes
Φ_2	Second star azimuth angle with respect to Topo-centric axes.
λ_2	Second star elevation angle with respect to Topo-centric axes.
V_2	Second star unit vector with respect to NWZ axes
Φ_{1_c}	First star azimuth angle with respect to Camera body axes
λ_{1_c}	First star elevation angle with respect to Camera body axes
V_{1_c}	First star unit vector with respect to Camera body axes
Φ_{2_c}	Second star azimuth angle with respect to Camera body axes
λ_{2_c}	Second star elevation angle with respect to Camera body axes
V_{2_c}	Second star unit vector with respect to Camera body axes
θ	Rotation around camera bore-sight.

Abstract

The main objective of this thesis is to estimate the satellites initial condition, for both of artificial and natural satellites, using optical observations.

Satellite Estimation process is the process in which we can correctthe knowledge about the satellite initial condition, or get a very accurate initial condition, which can be used for further propagation, may be, up to two weeks.

The Orbit Estimation (Initial Condition updating process), can be done via different types of observations, GPS measurements (satellite Position), Radar measurements (satellite range and range rate), or optical observations (Satellite Azimuth and Elevation).

Satellite's Initial Condition is represented by the satellite position and velocity at certain time. Where the position and velocity can be described with respect to any reference system of axis (Inertial, Greenwich coordinate system, etc…).

Many techniques can be used in order to correct the Initial condition usingoptical measurements. These techniques can be Least squares, and Genetic algorithms. These different types were discussed in order to find the best technique to correct the Satellite initial condition using optical observation.

Another important issue were handled, which is; how we can get Satellites' Azimuth and Elevation measurements (optical measurements) using low cost commercial equipment.

Satellite's orbit estimation process with optical observations, has unique privileges than other estimation process using the GPS or radar measurements. Where, optical observation is suitable for both artificial and natural satellites, operated and non-operated satellites. Also, optical observation is the unique solution in case of GPS or radar system malfunction.

Chapter 1. Introduction and literature review

In this thesis, through Chapters 1 to 4,we are going to discus, How to get a satellites' optical measurements form optical observation tools. In Chapter 5, we will use these optical measurements to correct the satellite initial condition using least squares and Genetic algorithm.

1.1Introduction

Satellite orbit Estimation is the process used to correct the satellite state vector (satellite position and velocity) or the six orbital parameters. Generally, the Estimation process is done by finding the best satellite states which fits with the measurements. Satellite measurements can be position and velocity (GPS measurements), range and range rate (radar measurements) [4], or azimuth and elevation (optical observation measurements).

In our case the observations are the satellite azimuth and elevation. Optimization is used to correct or estimate our initial condition. Optical observation has advantage over other techniques as it works with natural and artificial satellites. It also works in case of satellite malfunction.

Satellite optical measurements are the satellite's azimuth and elevation versus time. Such measurements cannot represent satellite position in the space, due to the lack of ranging measurements. So, these measurements considered to be weakly observable measurements. Large number of accurate observations is required to find a corrected initial condition near to the real one. Also, camera calibration is an essential process in order to get accurate measurements. Both of camera focal length [6] and camera attitude [1] are required to be calibrated.
Optimization algorithms work with limited accuracy measurements and can correct large errors in initial conditions. In this work, Genetic algorithms (Gas) will be used for optimization.

In our optical observation case, the number of sessions is less than four sessions per day and the duration is less than 8 minutes per session. Because, there is a constraint, we need the satellite to be in the sun light and the observer to be in the earth shadow or night, see Figure 1-1. Not only to be in the visible zoon in order to be optically observed.

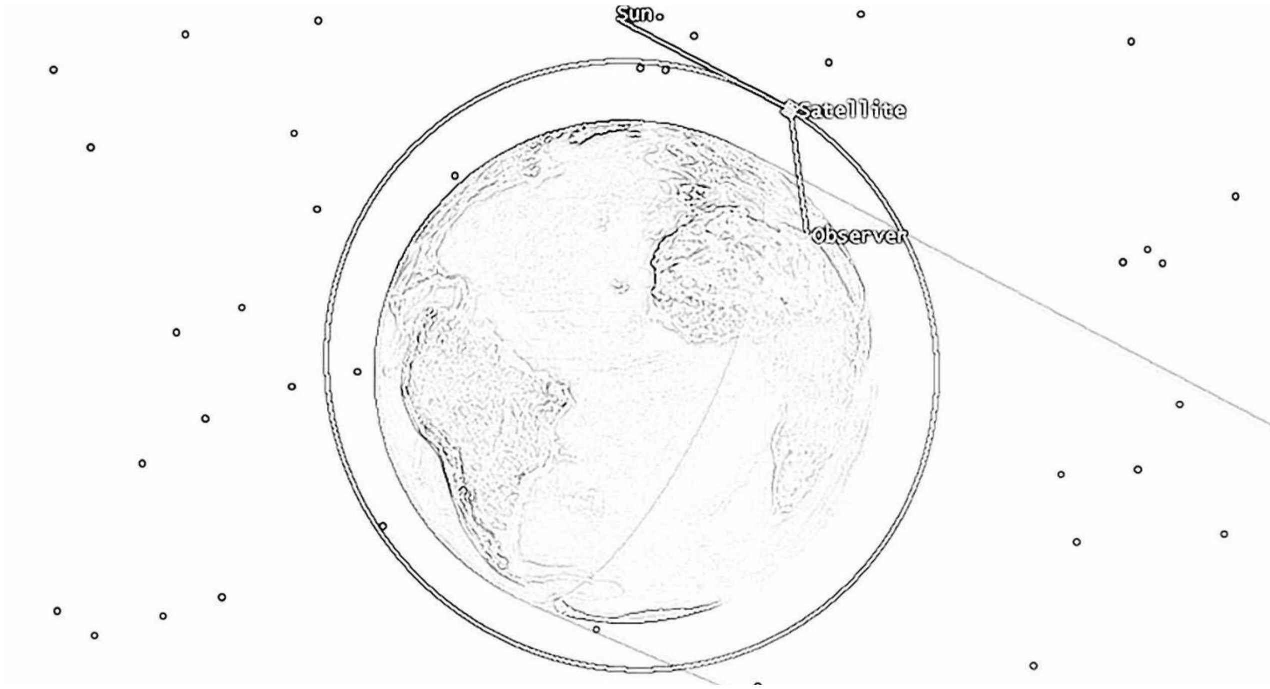

Figure 1-1 : Satellite Imaging Condition

The satellite observation tool (imaging) is a commercial camera (we used the commercial camera (Benq GH600)).Very primitive mount is used. Cost is about 150 USD).Figure 1-2, shows us an example of the International Space Station (ISS)passing above Egypt (Location at Latitude: 30° 14`55``, Longitude: 31° 21` 7``) in 09/11/2014.

Figure 1-2 : The ISS Passing above my home

Referring to Fig. 1-2, the ISS Pass appears surrounded with stars and plants, this image is color inverted to be able to be printed. The measurements extracted from this image need to be created in a table form, azimuth and elevation versus time.

Where, the 1st column represent the time in second from the start of the day, corresponding to Greenwich local time (the difference between Greenwich and Cairo is +2 Hours).

The 2nd column represent the satellite Azimuth angle measured with respect to "North-West-Zenith" NWZ system of axes, seeFigure 1-3.

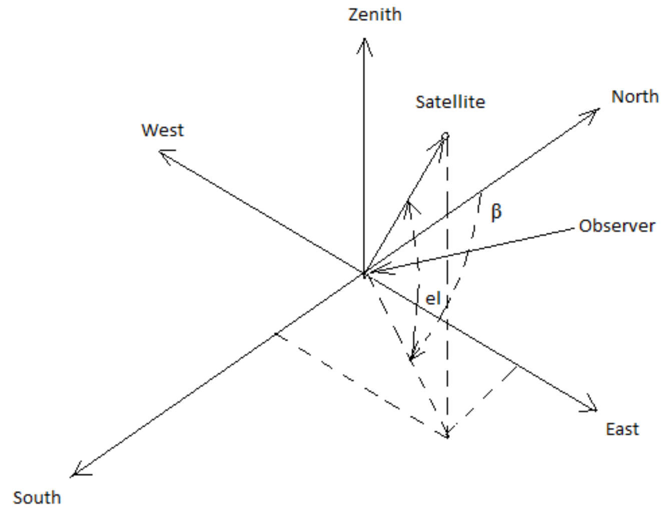

Figure 1-3 : SatelliteAzimuthand Elevation

Where; β : is the Satellite Azimuth angle.

el : is the satellite elevation angle.

The 3rd column represent the satellite Elevation angle measured with respect to "North-West-Zenith" NWZ system of axes, see figure3.

Methods to extract the azimuth and elevation measurementsfrom the image in Figure 1-2 will be discussed through chapter 1 to 4.