Geolocation Based on TDOA Measurements to Formation Flying Spacecraft

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Abstract — The GPS and the GLONASS are the most used satellite systems for localization and navigation. Position estimation is a very important task in the globalized world, and there are several techniques to accomplish this. The method used in this work is based on the Time Difference of Arrival (TDOA) measurements. Both GPS and GLONASS are satellite constellations, but the formation flying is a topic being studied a lot in the last years. This work used a satellite formation flying of 3 satellites in a circular orbit to geolocate an object on Earth's surface. A reconfiguration maneuver using the two-impulse method is made and its impact on locating the object is analyzed. With the results, it was possible to conclude that the further the orbit passes above the real object, the higher is the error. Also, the reconfiguration maneuver did not have much impact on the location error in latitude and longitude.

I. INTRODUCTION

The Global Navigation Satellite Systems (GNSS) is a constellation of satellites that provide signals that are used to determine location [1]. Geolocation can be performed using Time Difference of Arrival (TDOA) measures of a transmitted signal to or from a number of satellites which their positions are known [2]. With these measures, a set of nonlinear equations need to be solved to give the object position estimate. The number of satellites being used for position estimation heavily impacts on how the problem is treated, for 3 satellites the equations are simpler, but when dealing with 4 or more the equations take on more difficulty. Formation flying aims at achieving the functionality of a very large satellite with multiple small satellites and is a new paradigm in space missions [3]. Currently, there are satellite constellations, such as GPS and GLONASS being used as navigation systems as positioning. In the formation flying area of study, the satellites can have different configurations and can also perform several maneuvers. Each configuration and maneuver has its own specificities that can have a positive or negative influence on various aspects. The formation flying simulated in this study uses 3 satellites, one chief and two followers, and considers a projected circular orbit (PCO). The maneuver studied in this work is the two-impulse formation reconfiguration, where there is an initial and a final orbit, and two impulses are applied to take the deputy satellites from the first orbit to the second one.

Problem Definition

The possibility of using a spacecraft formation flying for aerial navigation, such as augmentation systems, can have advantages and present lower errors in the final result, such that using more satellites than the ones in GPS has presented good scenarios [4]. Since it is possible to have different sets of configurations and maneuvers, it is possible to have several different combinations. This work proposes the study of a geolocation mission using a spacecraft formation flying with the capacity to perform TDOA measurements and reconfiguration maneuvers. The study includes a simulation of the formation flying with different orbits passing through a receiver located at Santa Helena's Farm in Pindamonhangaba, Brazil, and estimating the receiver's position. Expectantly, it will be able to notice the influence of different formation configurations in the geolocation.

Objectives

The objectives of this work include:

- Study of geolocation using TDOA measurements;
- Study satellite formation flying for geolocation;
- Study of the impact of formation parameters have on geolocation;
- Study of the impact of formation reconfiguration maneuver on geolocation.

II. TDOA

For the TDOA approach, a minimum of 3 satellites is required to avoid ambiguous positioning [5]. With these satellites with known positions, the two TDOAs of a signal received by satellites define two hyperboloids in which the object must lie. Since the object is on Earth, the intersection of the two curves on Earth's surface defines the object's position.

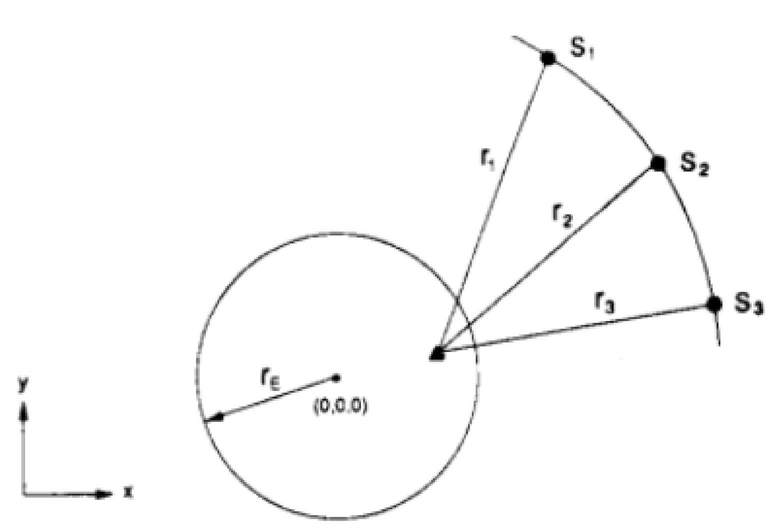

Fig. 1. Geolocation by satellites [5].

III. FORMATION FLYING

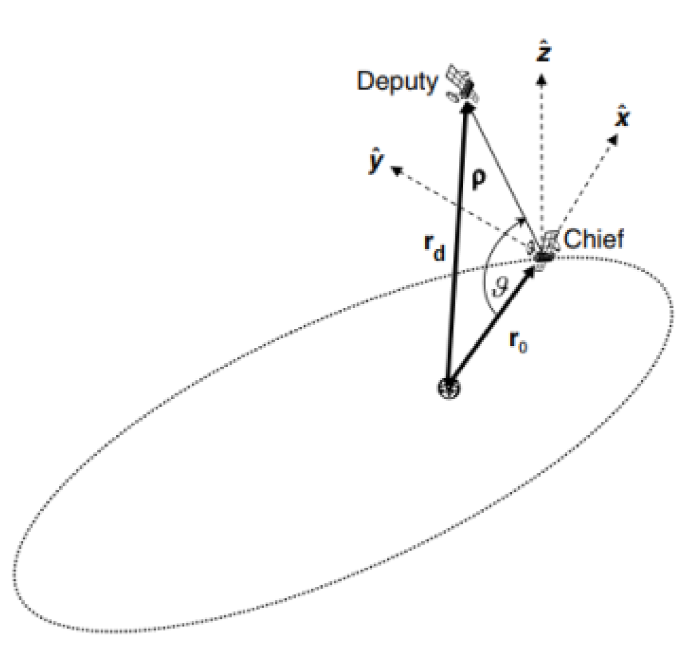

Fig. 2. Rotating frame centered at the chief spacecraft [6].

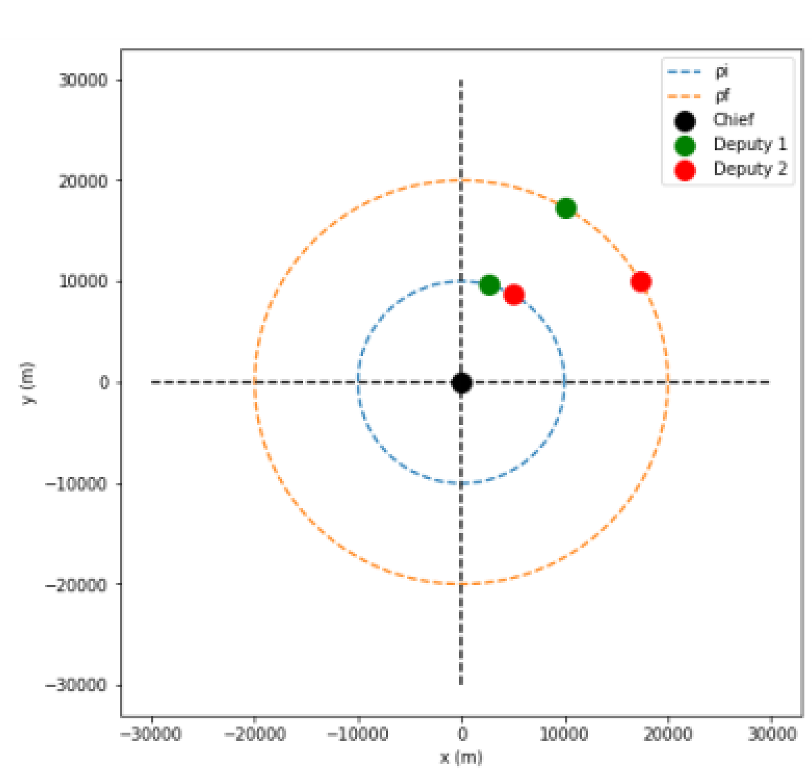

Fig. 3. Deputies location before and after reconfiguration.

IV. METHODOLOGY

TABLE I

ERROR (E. LAT, E. LON) ESTIMATION AND Δv COST FOR EACH SIMULATION.

Simulation	1	2	3	4	5	6
E. Lat BR (°)	5.10	0.70	0.72	5.10	0.14	0.72
E. Lon BR (°)	7.14	0.89	0.66	7.14	1.03	0.66
E. Lat. AR (°)	5.11	0.70	0.76	4.97	0.56	0.69
E. Lon. AR (°)	7.17	0.89	0.62	7.32	0.95	0.69
Δv_1 cost (km/s)	0.0016	0.0016	0.0016	0.0060	0.0065	0.0022
Δv_2 cost (km/s)	0.0003	0.0003	0.0003	0.0014	0.0015	0.0005

Fig. 4. Ground-track orbits chosen for the simulation.

VI. RESULTS

TABLE II

SIMULATION INITIAL PARAMETERS.

	Sim. 1	Sim. 2	Sim. 3	Sim. 4	Sim. 5	Sim. 6
a (km)	26561	26561	26561	26561	26561	26561
e	0	0	0	0	0	0
i (°)	56.09	106	56.09	56.09	106	56.09
Ω (°)	138.6	138.6	129	138.6	138.6	129
ω (°)	64	64	64	64	64	64
M (°)	122.15	122.15	122.15	122.15	122.15	122.15
ρ_f (km)	20	20	20	50	50	20
α_{i_1} (°)	15	15	15	15	45	45
α_{i_2} (°)	30	30	30	30	60	60
Orbit No.	1	2	3	1	2	3

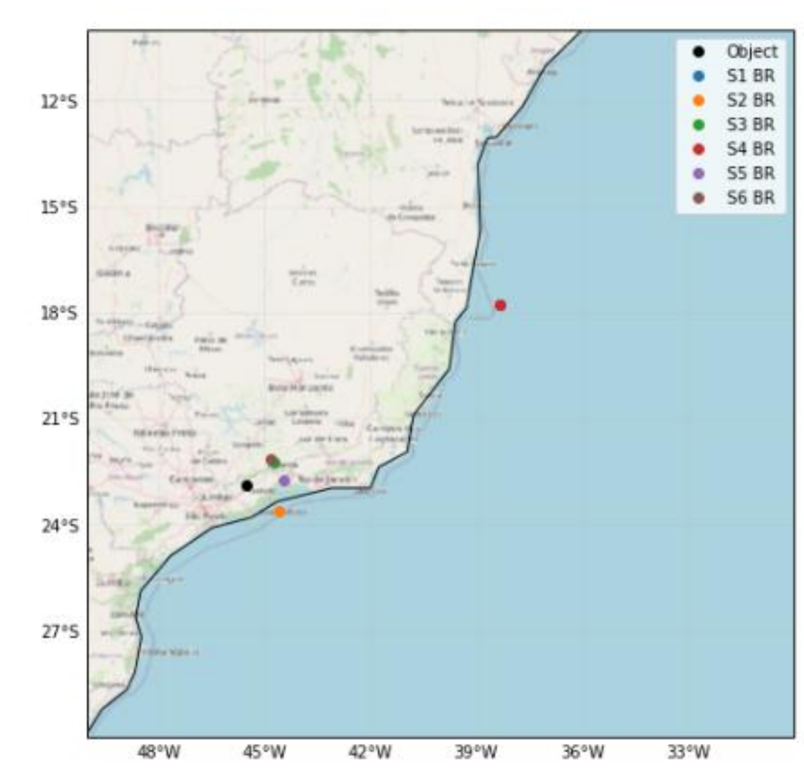

Fig. 5. Object's location and position estimate for all 6 simulations before recongiuration.

VII. CONCLUSION

All the objectives listed in Section I were met. The study about TDOA and geolocation was made and successfully implemented, along with a formation flying with 3 satellies realizing reconfiguration maneuvers. The simulation confirmed that the closed the orbit passes through the object, the more accurate the position is estimated. The maneuver of reconfiguration had little impact on geolocation, such that from all 3 orbits, the change in accuracy was barely noticeable. For all 6 simulations, whenever the error in latitude estimation decreased, the error in longitude increased, showing that it is a compromise. From the Δv cost analysis, it was possible to observe that the greater the final radius of the formation after the reconfiguration, the greater is the cost, as expected. The phase angles also have an influence in the final cost, but not as greater as the radius.

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