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Performance Analysis of GNSS System by Tracking the Position Deviation under Spoofing

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Abstract: We know that GPS is continuously becoming a more widely used technology in common life, so many are looking for unique ways to enhance innovations in this technology. Pseudolites (short for pseudo-satellites) are transmitters which are located locally on Earth and they transmit GPS satellite signals intermediately in order to allay for the GPS system in locations where satellite signals may be obstructed. When pseudolite signals are broadcasted or propagated in the form of pulses it is a better method to overcome the near-far problem which is their main limitation. The main aim of this is to paper explore the use of multiple pseudolites broadcasting pulsed signals, and their effects on the signal acquisition capabilities of GPS receivers using simulation. This paper explores the different methods of detecting the satellite in both the active and passive detection and also the different methods involved in propulsion of a satellite and thus observe which method is best suited for the practical uplift of satellite from earth's orbit into the space.

Keywords: GNSS (Global Navigation Satellite System), Propulsion, Pseudolites, GPS (Global Positioning System).

I. INTRODUCTION

In satellites a significant portion of the launch weight and the major determining factor in life span estimates is the amount of propellant that is used for navigation and station keeping. Many different methods can be employed to improve this [6]. In this paper we will explore autonomous detection of objects and navigation [1]. This limiting factor is the amount of propellant the satellite can carry. While it makes up a significant portion of the launch weight, there is a limit to how long it can last. Propellant is critical for navigation and station keeping. How efficiently it used is critical to extending the lifespan of satellites to the point where the electronics lifespan can actually be tested. Collisions are another critical thing to consider in satellite operational life spans as more objects enter space, while it is possible to track objects in space not always does the information get from those who are doing the tracking to those who need the information. There are quite a few methods that can be used to improve the efficiency of propellant use. The best researched and developed is to use a more efficient propulsion system. Another method just getting started is using autonomous guidance systems on the satellites themselves. What this paper proposes to explore is to combine this with on board detection systems using radio signals to detect objects in space around the satellite.

II. ALGORITHM

Step1: Detecting of satellite

The satellite is detected in its orbit by sending a radio signal and comparing the operation of a unidirectional radio transponder system with GPS. This is done using active detection.

Step2: Finding the Velocity, Acceleration and Orbital Velocity.

From the information obtained in the first step which is nothing but round trip time, we calculate the velocity, acceleration and orbital velocity by continuously tracking the satellite position.

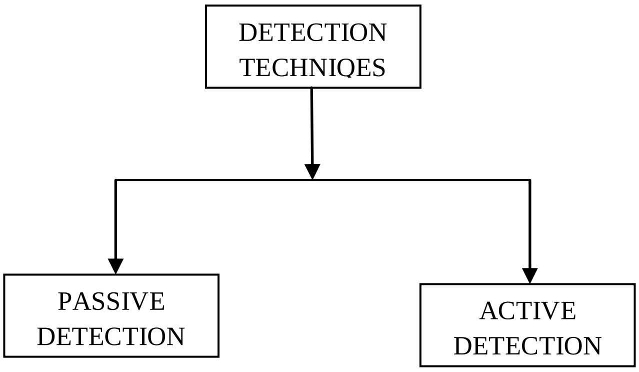
Step3: Application of different Propulsion Methods.

In this Step we apply different propulsion methods including both chemical and electrical methods for uplifting the satellite into its orbit.

Step4: Comparing different propulsion methods

In this section we will calculate the thrust several systems currently available are able to generate and compare them to find the best combination for efficiency.

III. DETECTION TECHNIQUES



1. Passive Detection

A radio location method that many people may be familiar with is passively detecting a signal source by triangulation. In a situation where the antenna is either largely unidirectional or has its position fixed, in case of a satellite, a different method has to be employed. In the case of a GPS receiver, the method employed is called trilateration. With line of sight distance to the GPS satellites being within 12,900 miles or 20,760 km. Each GPS satellite transmits its own time and position data in all directions creating a sphere. With data from two satellites you find the intersection of two spheres which forms a circle. This is why a third satellite's information is required because the new sphere will intersect the surface of the circle in only two points, with only one being on earth's surface and the other being out in space. This is the basics of how the position is determined with GPS.

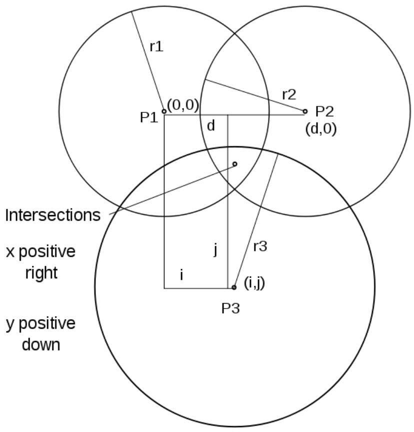
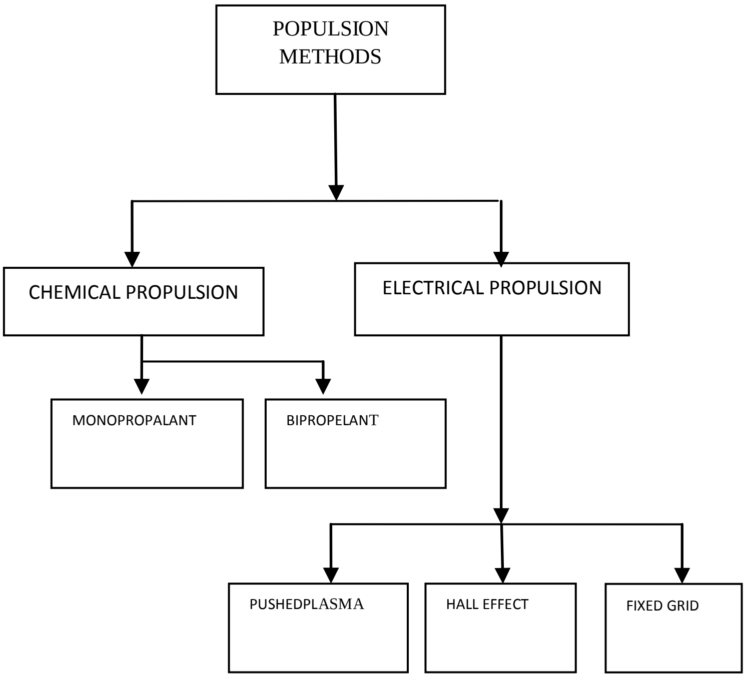


Fig:1: The plane, z=0, showing the 3 sphere centers, P1, P2, and P3; their x, y coordinates; and the 3 sphere radii, r1, r2, and r3. The two intersections of the three sphere surfaces are directly in front and directly behind the point designated intersections in the z=0 plane.

2. Active Detection

With passive detection to determine only an objects position in three dimensional spaces, such as low earth orbit, you would need a minimum of four or more antennas. With active detection this number can be reduced. Let's consider the situation with a single antenna transmitting and receiving. When the signal reflects from another object in space and returns, the only information we can be certain of is the round trip time. If the satellite was not in motion, this would give us that the object lies somewhere in a spherical shell with radius R, defined as half the elapsed time, times the speed of light in a vacuum. Since the satellite is in motion it becomes a three dimensional ellipsoid defined by all the possible intersecting circles of a sphere of arbitrary radius (r), centered at the transmit location, and a second sphere of radius (2R - r) centered at the receiving position.

IV. Propulsion Methods



1. Chemical propulsion methods

The most simplistic method of propulsion in space would be to use jets of compressed air. While this is very simple to control it has minimal energy and is incredible mass inefficient.

A. MONOPOPELLANT:

A Monopropellant solid-fuel rocket is a rocket engine that uses solid propellants (fuel/oxidizer).The earliest rockets were solid-fuel rockets powered by gunpowder. The solid-fuel rockets can remain in storage for long periods, and then reliably launch on short notice, The lower performance of solid propellants (as compared to liquids) does not favor their use as primary propulsion in modern medium-to-large launch vehicles customarily used to orbit commercial satellites and launch major space probes[7]. This is the advantage of the solid rocket in that the combustion reaction continues without the need for external oxygen and gives it an advantage in the heavy lift operation to move space vehicles into orbit. It is also its limitation for long term usage in orbital navigation and station keeping.

B. BIPROPELLANT

In the bipropellant rocket the liquid fuel and a liquid oxidizer are stored in separate tanks until combined in a reaction chamber [8]. The bipropellant Rocket is also noted for having a higher thrust capability then comparable solid rockets. Because the fuel and oxidizer are separated the combustion reaction can be cut off and restarted almost at will, as well as controlling the actual combustion rate. The design of a liquid rocket is far more complex when compared to a solid rocket [9].

2. Electric propulsion methods

Ion thrusters are a form of propulsion that uses electricity either from solar cells or a nuclear reaction to create thrust by accelerating ions. While they are very mass efficient the thrust they generate is very small when compared to chemical rockets. This makes them operate on longer time scales. They fall into two major type categories, dependent on the method they use to accelerate the ions, Electrostatic and Electromagnetic.

- PUSHEDPLASMA THRUSTER

The thruster operates in a two stage process, first a capacitor called the energy storage device, discharges between electrodes close to a solid propellant. This spreads across the surface of the propellant ionizing it. A magnetic field accelerates this new plasma away from the electrodes and the current between the electrodes from an external power source continues ionizing the solid propellant. A simple spring put pressure on the solid fuel rod to keep the surface close to the electrodes. They use an electric field to create the plasma. Acceleration is created by a combination of the electric field and an additional magnetic field interacting with each other

- HALLEFFECT THRUSTER

The Hall Effect is simply the deflection force observed on a conductive material in the presence of a magnetic field. The basic design of a Hall Effect thruster uses a solid circular anode and a magnetic coil to create a containment field for the hot plasma. This is then pushed away from the positive anode. A stream of electrons is shot into the expelled gas to neutralize the ions and serve as the cathode.

- FIXED GRID THRUSTER

The way a grid type thruster works is a propellant is released into a chamber around an electron gun, just like in the cathode ray tube in older television sets, is used to ionize the gas. By diffusion the now positively charged ions then move through a grid that has a positive electrical potential. Once passed the first grid the ions are accelerated past another grid with a negative electrical potential.

V. GNSS NAVIGATION IN OBSCURED AREAS

Global Navigation Satellite Systems (GNSS) is widely used in various industries and many innovations are continuing to emerge. Pseudolites are “auxiliary” or “subsidiary” ground based transmitters that perform similar function of a GNSS satellite by transmitting GPS-alike signals, which are localized often from the ground [10]. They have potential to implement GNSS technology in regions where GNSS are not applicable. In spite of these capabilities, pseudolites cause several interference problems to the one’s which are inactive. The introduction of local signals has several problems. One of the largest problems which evolve commonly is known as the near-far problem. Pseudolites signals are similar to satellite signal, but the problem is satellites signals are transmitted from a distance which are thousands of kilometers away, while pseudolites are very near to the user. This can pose a problem of the pseudolite signal overpowering the satellite signals when the user is too near; but if a user is located too far from the pseudolite the opposite occurs and the signal will be too weak for the receiver. One solution to avoid near-far problem is transmitting pulsed signals from the pseudolites, a type of Time Division Multiple Access (TDMA).The maximum number of pseudolites tested is four since that is the required number of satellites for full positioning capabilities. Through similar reasoning, three GPS satellites are present, as this would be necessary if only one pseudolite is operating.GPS satellites output signals are generally present in two forms namely, the Coarse Acquisition Code (C/A Code), and the encrypted Precision Code (P(Y) Code).The codes employ a form of Code Division Multiple Access (CDMA) so they can be transmitted at same frequency.

VI. RESULTS

CALCULATIONS OF ACCELERATION

Now we come to the heart of the problem. For any propulsion system to be effective for avoidance maneuvering it has to successfully move the craft out of the way of a collision. Even a difference of a few meters can spell the difference between a collision and a miss. The question is can the propulsion system achieve that from the time of detection or not. Now we compare the different propulsion methods by the actual acceleration they provide. Since we have no real numbers to work with the theoretical propulsion methods will not be considered. The same goes for systems that are not used such as simple compressed gas. We have to consider several different situations on avoiding a collision. In the end all of them can be reduced all of them have a different amount of time until collision. In space the worst case scenario and the most unlikely situation is the classic head on collision. This is the situation where we have the absolute least amount of time. If we have two satellites traveling at escape velocities, for simplicity say 10 kilometers a second, traveling on the same orbital path towards one another then at a range of two hundred kilometers. As the relative velocity with then be 20 kilometers a second we have a total of ten seconds to adjust the trajectory for our satellite. This is a hypothetical situation.

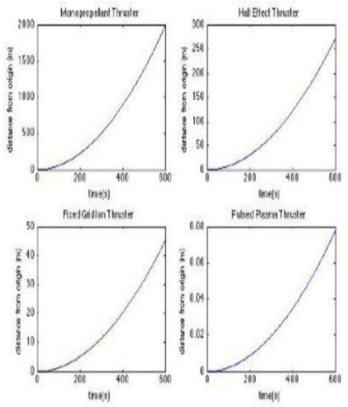


Fig2: Comparison of displacement over a set time in Matlab

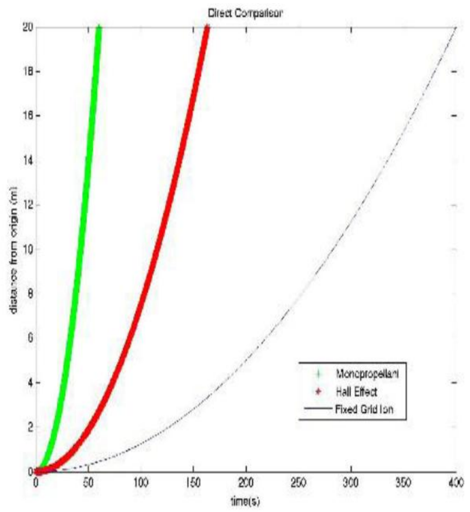


Fig3: Direct comparison of displacement versus time for several thrusters created in Matlab

VII. Conclusion

A detection system that uses unidirectional antenna transmitting a transmission time stamp is feasible. The computing power required can be minimized by concentrating on the highest probability targets and relaying all other information back to the ground station for further processing. The propulsion system that would seem to be best to work with this system would be Hall Effect thrusters with monopropellant thrusters for emergency backup.

While pseudolites can bring many benefits to GPS users, it must be ensured that nearby GPS receivers not intending to use them do not experience interference. If pseudolites are placed in remote locations (as most uses would require anyways), this is not a large concern, as receivers beyond a reasonable distance would not experience signals of significant power. Further investigation should be done into pseudolite placement to allow sufficient GPS augmentation without interruption of signal to other receivers nearby. Pseudolite blanking provides a promising technique to allow GPS receivers to operate in environments with multiple pseudolites. However, it does require hardware upgrades to receivers. Research into cost effectiveness for specific uses should be conducted to test feasibility.

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