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SOME ASPECTS OF ARTIFICIAL BODIES STABILIZATION AND ORIENTATION

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Abstract. To increase energy resources, and thus the overall possibility of modern cosmic aircrafts, power supply was expanded by adding the (moving) wing area and antenna with complex orientation and design. It is clear that all of this, when there is a need to conduct a very accurate account of orbital elements of satellites, is a nightmare for the experts and scientists. In this paper we will give special attention to the system of stabilization and orientation of satellites, as well as to the importance of gyroscopic effects and the navigation systems of the artificial celestial bodies. Development of modified practical solutions based on knowledge and experience with gyroscopic effects is immeasurable.

1. INTRODUCTION: SPUTNIK STARTED IT ALL

Artificial bodies, such as satellites, are used to study the Earth, other planets, to help us communicate, and even to observe the distant Universe. Satellites can even have people in them, like the International Space Station and the Space Shuttle. The first artificial satellite was the **Soviet Sputnik 1** mission, launched in 1957.

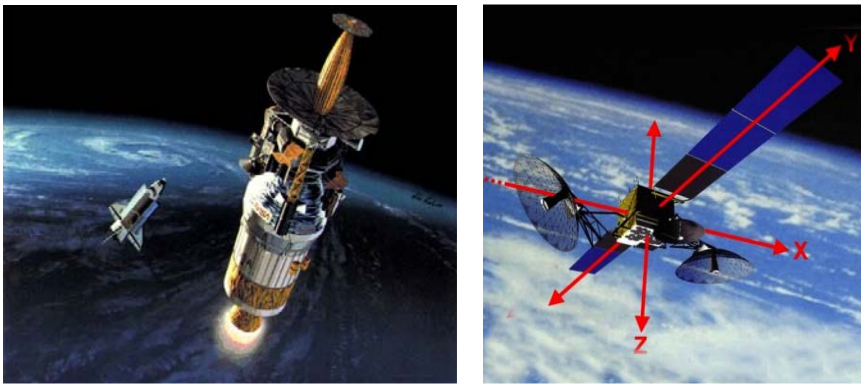
Satellites are launched into different orbits depending on their mission. One of the most common ones is geosynchronous orbit. This is where a satellite takes 24 hours to orbit the Earth; the same amount of time it takes the Earth to rotate once on its axis. This keeps the satellite in the same spot over the Earth, allowing for communications and television broadcasts. Another orbit is low-Earth orbit, where a satellite might only be a few hundred kilometers above the planet. This puts the satellite outside the Earths atmosphere, but still close enough that it can image the planets surface from space or facilitate communications. This is the altitude that the space shuttle flies at, as well as the Hubble Space Telescope. Artificial satellites can have a range of missions, including scientific research, weather observation, military support, navigation, Earth imaging, and communications. Some satellites fulfill a single purpose, while others are designed to perform several functions at the same time.

2. ATTITUDE AND ORBIT CONTROL

In order to control an autonomous vehicle, it is fundamentally important to know its attitude. For manned aircraft, roll, pitch and yaw can be obtained through orientation by an inertial reference, usually the ground, or instruments such as an artificial horizon or a compass. Still all of them are dependent on pilot interaction. For unmanned platforms, it becomes necessary to use an electronic device capable of measuring physical quantities related to that goal. A device that aggregates these sensors is called IMU (Inertial Measurement Unit). An IMU contains inertial sensors that measure linear acceleration and angular rate, among other physical data. Through reading and fusing these data it is possible to obtain attitude information which, applied to flight history, can help to determine the position relative to an initial position in a way that allows an aircraft to be stabilized or maneuvered to follow a predetermined trajectory, fulfilling the role of replacing a pilot. Attitude control is essential to prevent the satellite from tumbling in space. Attitude of a satellite is its orientation as determined by the relationship between its axes (yaw, pitch and roll) and some reference plane.

3. SATELLITE STABILIZATION

The satellite once placed in its orbit, experiences various perturbing torques. These include gravitational forces from other bodies like solar and lunar attraction, magnetic field interaction, solar radiation pressure, etc. Due to these factors, the satellite orbit tends to drift and its orientation also changes. The satellite's position thus needs to be controlled both in the east-west as well as the north-south directions. The east-west location needs to be maintained to prevent radio frequency (RF) interference from neighboring satellites. It may be mentioned here that in the case of a geostationary satellite, a 10 km drift in the east or west direction is equivalent to a drift of about 735 km along the orbit. The north-south orientation has to be maintained to have proper satellite inclination. The attitude and orbit control system maintains the satellite position and its orientation and keeps the antenna correctly pointed in the desired direction. The orbit control is performed by firing thrusters in the desired direction or by releasing a jet of gas. It is also referred to as station keeping. Spin stabilization (shown in **Figure 1a**) and three-axis stabilization (shown in **Figure 1b**) are two methods that are used to orient satellites.



(a) Spin stabilization

(b) Three - axis stabilization

Figure 1: Satellite stabilization (a) and (b).

3. 1. SPIN STABILIZATION: SOME FACTS

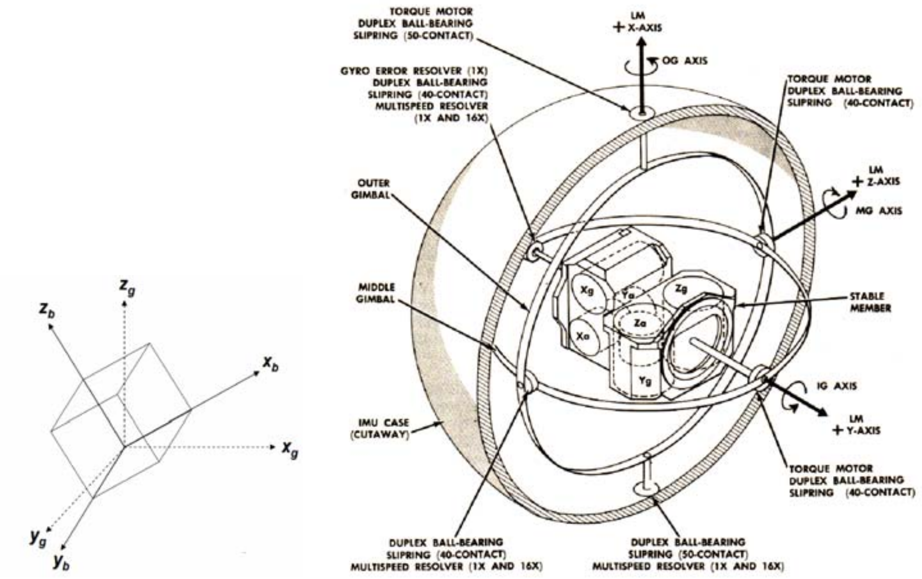
With spin stabilization, the entire spacecraft rotates around its own vertical axis, spinning like a top. To maintain stability, the moment of inertia about the desired spin axis should be at least 10% greater than the moment of inertia about the transverse axis. The advantage of spin stabilization is that it is a very simple way to keep the spacecraft pointed in a certain direction. The spinning spacecraft resists perturbing forces, which tend to be small in space, just like a gyroscope or a top. Designers of early satellites used spin-stabilization for their satellites, which most often have a cylinder shape and rotate at one revolution every second. A disadvantage to this type of stabilization is that the satellite cannot use large solar arrays to obtain power from the Sun; thus, it requires large amounts of battery power. Another disadvantage of spin stabilization is that the instruments or antennas also must perform "despin" maneuvers so that antennas or optical instruments point at their desired targets. Spin stabilization was used for NASA's Pioneer 10 and 11 spacecraft, the Lunar Prospector, and the Galileo Jupiter orbiter.

3. 2. THREE-AXIS OR BODY STABILIZATION

The stabilization is achieved by controlling the movement of the satellite along the three axes, i.e. yaw, pitch and roll, with respect to a reference. The system uses reaction wheels or momentum wheels to correct orbit perturbations. The stability of the three-axis system is provided by the active control system, which applies small corrective forces on the wheels to correct the undesirable changes in the satellite orbit. Most three-axis stabilized satellites use momentum wheels. The basic control technique used here is to speed up or slow down the momentum wheel depending upon the direction in which the satellite is perturbed. The satellite rotates in a direction opposite to that of speed change of the wheel. For example, an increase in speed of the wheel in the clockwise direction will make the satellite rotate in a counterclockwise direction. The momentum wheels rotate in one direction and can be twisted by a gimbal motor to provide the required dynamic force on the satellite. An alternative approach is to use reaction wheels. Three reaction wheels are used, one for each axis. They can be rotated in either direction depending upon the active correction force. The satellite body is generally box shaped for three-axis stabilized satellites. Antennae are mounted on the Earth-facing side and on the lateral sides adjacent to it. These satellites use flat solar panels mounted above and below the satellite body in such a way that they always point towards the sun, which is an obvious requirement. Voyagers 1 and 2 stay in position using 3-axis stabilization. An advantage of 3-axis stabilization is that optical instruments and antennas can point at desired targets without having to perform despin maneuvers.

4. THE SCIENCE OF NAVIGATION

The science of navigation has played an important role for humanity. Since the 1940's navigation systems, in particular inertial navigation system (INS), have become important components in military and scientific applications. Inertial navigation is a self-contained navigation technique in which measurements provided by accelerometers and gyroscopes are used to track the position and orientation of an object relative to a known starting point, orientation and velocity. It is not subject to the line-of-sight problem inherent in many radio navigation systems, and is not affected by external jamming or spoofing. This non-radiating property of inertial navigation has led to the revolutionary development in technology to produce navigation systems for military and aerospace applications. These include guidance system for ballistic missiles, submarines, and space vehicles. The development of digital computers and micro-miniaturization of electronics systems arose largely from continuing requirements of inertial navigation systems for aerospace applications, for more accuracy, higher reliability, smaller size, and lower weight. An inertial measurement unit typically comprises of three orthogonally-positioned rate- gyroscopes, and three orthogonally-positioned accelerometers, measuring the angular velocity and linear acceleration components along each axis respectively. The fundamental principle of inertial navigation is simple, i.e. to measure the components of the vehicle's acceleration along precisely defined axes. However, the accuracy which must be achieved, and the inherent sources of error, makes practical systems inevitably complex. All IMUs fall into one of two categories. The classification is based on the frame of reference in which the rate-gyroscopes and accelerometers operate. The navigation system's frame of reference will be referred to as the body-frame (represented by **b**), while the inertial reference frame (in which guidance occurs) will be referred to as the global-frame (represented by **g**). This is schematically shown in **Figure 2a**.



(a) The body b and global g frames of reference

(b) A stabilized platform IMU system

Figure 2: Inertial navigation (a) and (b).

4. 1. STABILIZED PLATFORM

In stabilized platform systems, the inertial sensors are mounted on a platform which is isolated from any external rotational motion. The platform is held in alignment with the global frame. This is achieved by mounting the platform using gimbals/frames which allow the platform freedom in all three axes. An example of such a system is illustrated in **Figure 2b** (as deployed in the Apollo series of lunar space vehicles). The platform mounted gyroscopes detect any platform rotations. These signals are consequently fed back to torque motors which rotate the gimbals in order to cancel out rotations, hence keeping the platform aligned with the global frame.

Angle-pickoff readings are used to track the orientation of the device the angles between adjacent gimbals. To calculate the position of the device the signals from the platform mounted accelerometers are integrated twice. To obtain the actual acceleration experienced by the system, it is necessary to subtract the components of acceleration due to gravity. The gravitational components are evaluated from the measurements made by the on-board gyroscopes. A simplified version of the stabilized platform inertial navigation algorithm is outlined in **Figure 3**.

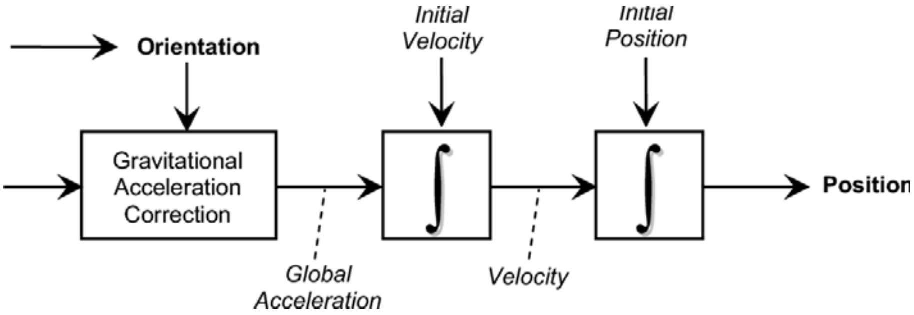


Figure 3: A simplified version of the stabilized platform inertial navigation algorithm.

4. 2. STRAPDOWN SYSTEMS

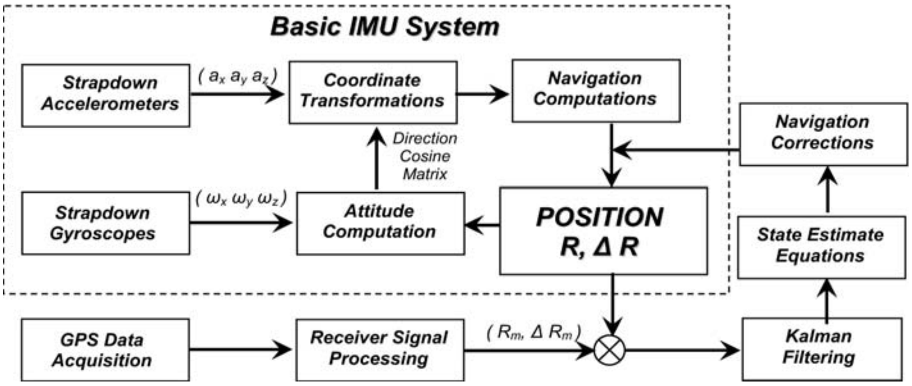


Figure 4: Basic block-diagram of a strapdown IMU system.

In strapdown systems, as schematically shown in **Figure 4**, the inertial sensors are mounted onto the device undergoing motion, and therefore output quantities are measured in reference to the body-frame (rather than the global-frame). To extract orientation, the angular-rate information extracted from the gyroscopes is integrated. To track the position, the three accelerometer signals are resolved into the global coordinates using the orientation information extracted from the rate gyroscopes. An outline of a conventional strapdown inertial measurement unit is shown in Figure 4. In general, most strapdown IMU are integrated with global positioning system (GPS) and internal navigation correction software to correct for errors accumulated by the drift of the inertial sensors. Both stabilized platform and strapdown systems are based upon the same underlying principles. Strapdown systems have reduced mechanical complexity and tend to be physically smaller than stable platform systems. These benefits are achieved at the cost of increased computational complexity. However, as the cost of computation has decreased exponentially, strapdown systems have become the dominant type of INS.

CONCLUSION:

The accuracy with which the required attitude must be maintained depends on the purpose the satellite has to serve. This accuracy largely dictates the choice of the method of attitude control. Several ways can be followed to describe the different control methods used in the past or contemplated for future use. A division according to the reference-system with respect to which the satellite's attitude must be constant, has been mentioned in the Section 4. Another useful manner to describe the various methods, distinguishes between passive and active control methods. The characteristic difference is, that passive methods - such as spin-stabilization - require no energy from the satellite, whereas systems based on active control methods have to be supplied with some kind of energy from the satellite.

Bibliography

Augenstein, B. W.: 1959, Dynamics Problems Associated with Satellite Orbit Control, *Trans. ASME.*

Blitzer, L. M. Weisfield and D. Wheelon: 1956, Perturbation of a Satellite Orbit due to the Earth's Oblateness, *J. Appl. Physics*, **27**.

David A. Vallado and Wayne D. McClain: 2001, Fundamentals of astrodynamics and applications, USA.

Frye, E.: 1958, Fundamentals of Inertial Guidance and Navigation, *J. Astronaut. Sci.*.

George M. Siouris: 2004, Missile Guidance and Control Systems, New York.

Jay A. Farrell and Matthew Barth: 1999, The Global Positioning System & Inertial Navigation, New York.

King-Hele, D. G. and Walker, D. M. C.: 1959, Methods for Predicting the Orbits of Near Earth-Satellites, *J. Interplanetary soc.*, **17**.

Marcel J. Sidi: 1997, Spacecraft Dynamics and control, Cambridge, 1997.

Mitsutomi, T.: 1958, Characteristics and Stabilization of an Inertial Platform, *Trans. IRE.*

William, Tyrrel, Thomson: 1986, *Introduction to Space Dynamics*, Dover publications, New York.