Absolute coordinate with Quadrant detector to track satellite from ambulance

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ABSTRACT

Tokai University has been conducting research on ambulances and related onboard systems for transmitting video images from vehicles in motion via the quasi-zenith satellite, which are scheduled to be launched by the Communications Research Laboratory (CRL) and the NASDA. This paper describes a newly-developed high-precision satellite tracking system, which we have developed for use with this system. The core of this tracking system comprises a few mutually complementing independent signal processing subsystems. Within this system, the absolute coordinates of the satellite are estimated by a quadrant detector(QD), while its relative coordinates are estimated by a GPS-based continuous kinematic positioning technique and calculations of six orbit elements. As we intend to use Ka-band transponder and to use narrow beam antenna of the vehicle. So here, we would like to discuss the effect of absolute coordinate with the quadrant detector to track satellite at urban area.

Fig. 1 GPS antenna for Continuous kinematic positioning

OBJECTIVE

We have designed and made a prototype of a satellite tracking system to be installed in emergency ambulances for tracking a quasi-zenith satellite.

SYSTEM

Target satellite

A geostationary satellite (GEO) may be used in areas near the equator and flat areas with few obstructions. For Japan, however, which is located 30 to 45(north latitude, a quasi-zenith satellite is most suitable for data transmission (i.e., uplinks to a satellite) from ambulances operating in urban areas, because such a satellite can avoid shadowing (blocking) and maintain a high angle of elevation for a long time. The quasi-zenith satellite referred to here will be a Quasi-Zenith Satellite (a 45-degree inclined synchronous orbiter).

Tracking mechanics

We have mounted on the roof of an ambulance two tracking systems that can operate in the 25-90 degree angle of elevation range and up to a continuous 660-degree azimuth range to track either a geostationary satellite or HEO. The drive system features a compact, simple design, and mechanically controls a Cassegrain antenna 50 cm in diameter (weight: kg; target radio bands: X, Ku and Ka; feeder unit: optional). Two DC motor systems for azimuth and elevation control are installed, and the reduction gears have a harmonic drive mechanism with non-backlash gears aligned on a single input/output line. A transmission belt links the harmonic drive and turntable.

Track systems

First, six parameters of the satellite's orbit are entered into an on-board computer, then the position gap detected by sensors is diminished step by step. Specifically, the on-board computer (running Linux) calculates the displacement of estimated satellite position from the true position based on data provided by input systems consisting of GPS sensors, an inclinometer, and a quadrant detector. Then, the computer generates an output signal to control the drive motors (of the azimuth and elevation control systems). The tracking method (with 3-5 operations per second) has a closed loop of sensors and motors. It first corrects 75% of the total positioning error, then performs fine-tuning based on feedback from the sensors. The following A-C sensors provide the tracking system with information about azimuth (AZ) and elevation (EL) control.

A. GPS interference positioning (Continuous kinematic positioning)

GPS interference positioning and continuous kinematic positioning are technologies used to receive signals simultaneously sent from GPS satellites at two sites, and to determine the relative coordinates of one receiving point against the other based on the measured phase of the carrier wave. We obtain directional data in 3D coordinates from three GPS receivers. The GPS interference positioning provides higher accuracy than the popular single positioning method or so-called translocation method. Such positioning can obtain relative coordinates approximating the absolute coordinates of the target satellite (particularly in the X-Y plane).

Features:

1. Receives carrier waves sent from GPS satellites with three antennas, then calculates phase shift.

2. Directional accuracy: one degree
3. Start-up time: three minutes
4. High-speed rotation: 25 degrees/sec
5. A proprietary three-antenna system that is less vulnerable to pitching or rolling
6. Prepares for instantaneous GPS signal interruptions by installing a gyro-compass as backup.

B. Quadrant detector

Data transmission from an ambulance to the satellite is the major part of data flow in the current system. However, concarrently with transmission four spatially separated receiving circuits (all located the same distance from the center of the Cassegrain antenna feeding unit) concurrently catch weak pilot beacons sent from the satellite. Four DSPs along the time axis integrate these received signals to calculate four magnitudes of electric power. The differences between these four values of arriving power are determined based on the beacon angle and four spatial coordinates(Fig.2-4). The output given to the drive system for fine-tuning of the azimuth and angles of elevation can then be calculated with reference to a conversion table covering each antenna pattern. For use under multipath conditions (e.g., with Nakagami-Rice fading, Loo fading), the quadrant detector works better than so-called monopulse antennas because it has an independent array structure (i.e., independent heterodyne receiver) . The monopulse antenna is widely used in a number of radar tracking systems to indicate the direction of arriving signals by a simple comparison of voltage amplitudes, and by integrating the voltage values of the same phase with those of the reverse phase. The quadrant detector provides the absolute coordinates of the satellite.

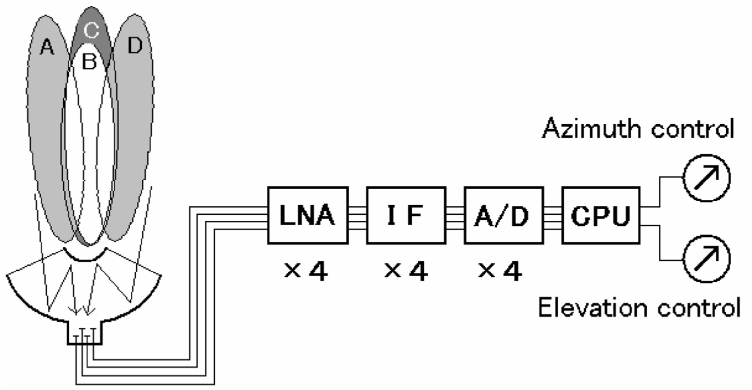

Fig. 2 System concept of Quadrant Detector

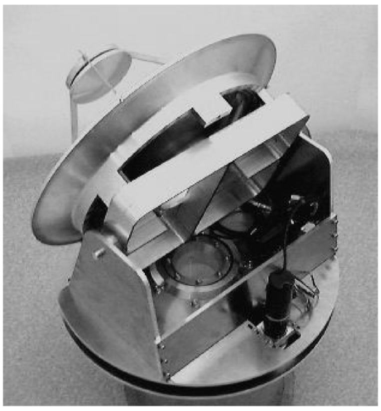

Fig. 3 On board antenna(40cm diameter Ku- Ka band)

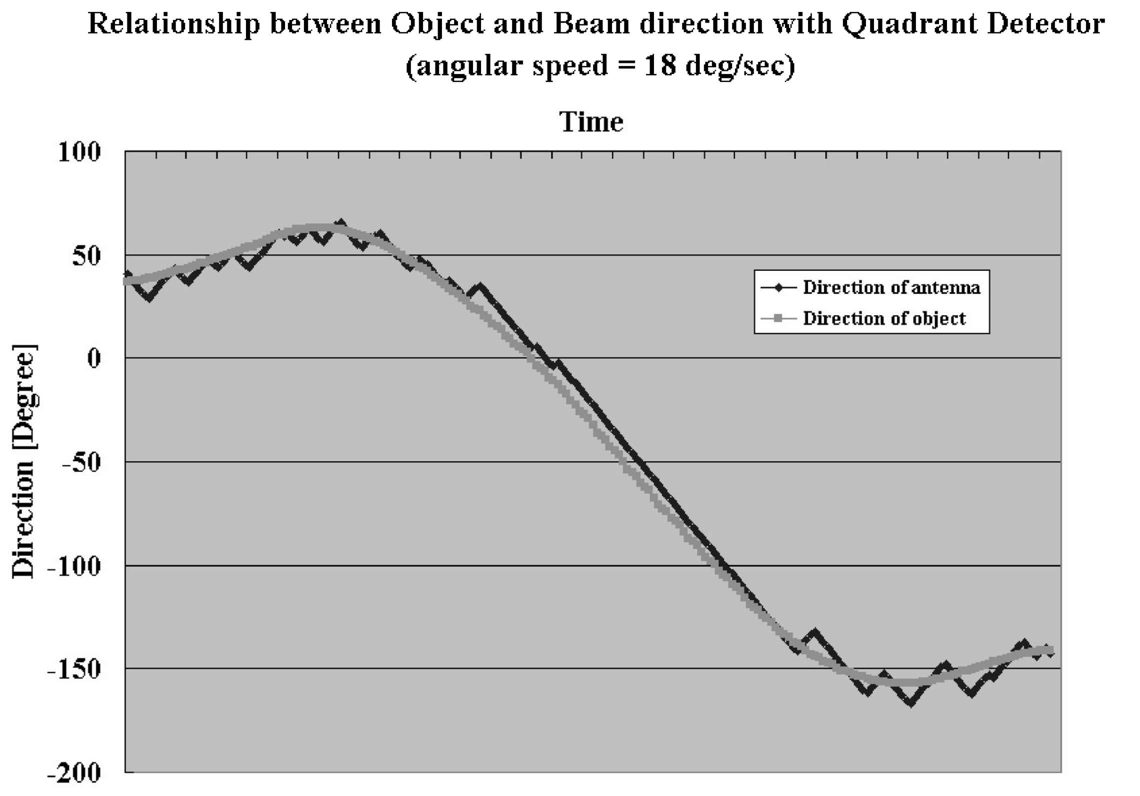

Fig. 4 Test results of the tracking accuracy of the Quadrant Detector

DISCUSSION

Tracking ability of the quadrant detector

Tracking a satellite requires knowledge of its coordinates. If the satellite is visible, we can obtain absolute coordinates. Relative coordinates can be obtained by calculating the position of the satellite based on the six orbit elements, and the direction of the running vehicle can be obtained by any means. This can be summarized as follows:

- Relative coordinates

Calculated from the six orbit elements and the direction of the vehicle. The calculation amounts to a rough approximation.
Tools and method: Optical-gyro, Magnetic sensor, D-GPS

- Absolute coordinates

Receive signals from the satellite and measure the angle of arriving signals (direct line of sight of satellite). Tools and method: Quadrant detector, Step-tracking, Mono-pulse method, Higher-order mode method.

A mono-pulse antenna, which uses the sum and difference in high-frequency signal level, is recommended for signals that show no feeding. In contrast, for moving objects that causes signal feeding, a diversity antenna (or independent two-array antennas) are highly effective. Combined use of two antennas with high-frequency signal levels. The receiving power is expressed by the following equation for the case wherein an ambulance moving underneath a plurality of evenly spaced electric wires (slit with an interval D) receives incoming waves at an angle θ :

$$I(\theta) = I(0)\left|\frac{\sin\left(\frac{\pi}{\lambda}D\sin\theta\right)}{\frac{\pi}{\lambda}D\sin\theta}\right|^2$$

Microwaves that have passed evenly spaced barriers are selectively received one by one, with results similar to that obtained by FFT expansion. Thus, if a mono-pulse antenna combining microwaves in the state of high frequencies (two or more trigonometric functions are combined) is used to receive feeding signals, the separation system is rendered worthless. Gaussian noise, whose expectation value is zero, can be removed by providing and integrating four independent signals along the time axis.

The quadrant detector outputs the coordinates of arriving signals by comparing the average receiving powers in the four independent systems. The resulting tracking ability was high enough for practical use,, which shows the quadrant detector's performance, obtained as the vehicle turned a 90-degree corner in five seconds.

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