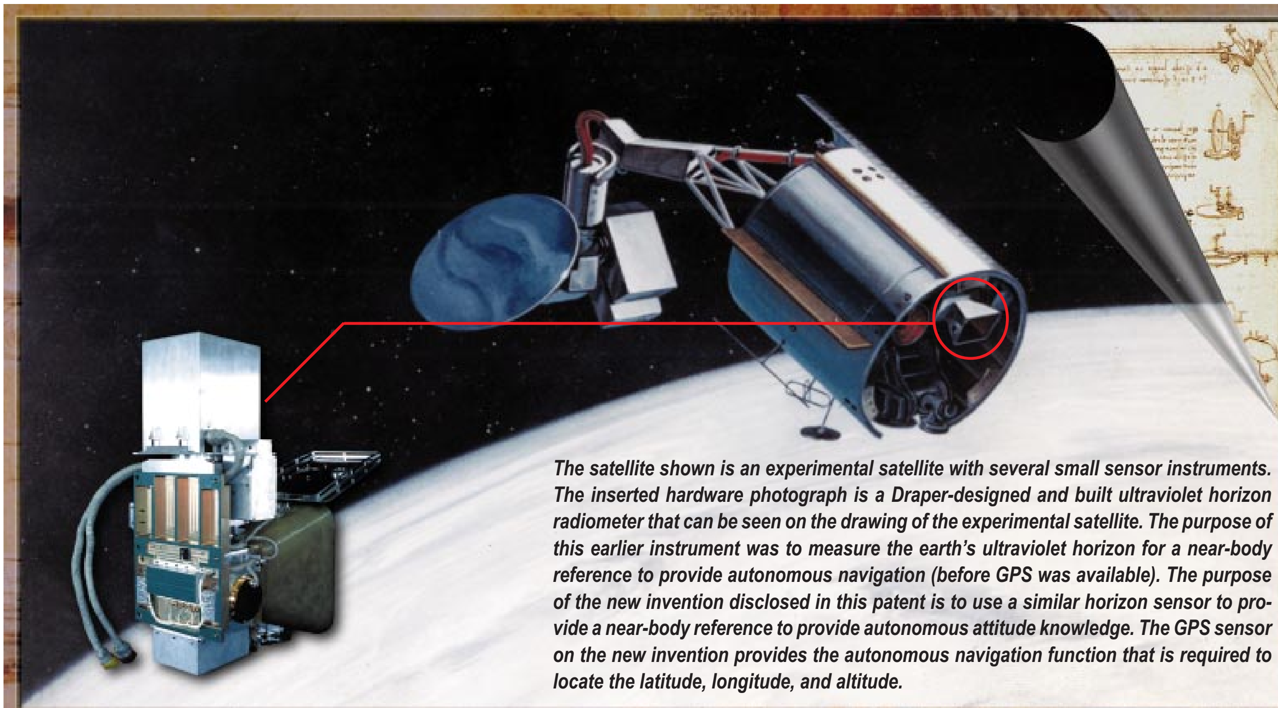

The satellite shown is an experimental satellite with several small sensor instruments. The inserted hardware photograph is a Draper-designed and built ultraviolet horizon radiometer that can be seen on the drawing of the experimental satellite. The purpose of this earlier instrument was to measure the earth's ultraviolet horizon for a near-body reference to provide autonomous navigation (before GPS was available). The purpose of the new invention disclosed in this patent is to use a similar horizon sensor to provide a near-body reference to provide autonomous attitude knowledge. The GPS sensor on the new invention provides the autonomous navigation function that is required to locate the latitude, longitude, and altitude.

Overview - Autonomous Satellite Attitude Sensing

Patent No. 5546309 **Issued 08-13-96**

Draper has long pioneered instrumentation for precision guidance, navigation, and control. The motivation for efforts leading to this patent was Draper Laboratory's interest in emerging technology for affordable, but capable, small satellites. Instrumentation is now available (Global Positioning System (GPS) sensors and small optical and inertial sensors and processors) that can be used in such satellites to accomplish the attitude sensing functions required to determine satellite orientation in a more cost-effective and reliable fashion than by traditional means. The apparatus and method described in this invention provide an approach for autonomous attitude determination that has the potential of being compact, accurate, and cost-effective. The invention could be applied to satellites for earth surveillance and for laser communications.

This patent describes an apparatus and method to perform autonomous satellite attitude sensing using GPS as the navigation device, sensing the earth horizon for a local vertical determination, and processing the attitude with a Kalman filter. No ground tracking stations are required. This autonomous attitude sensing function provides the local reference in latitude/longitude coordinates needed for earth surveillance. Also, the autonomous inertial attitude sensing function can be used to point satellite laser communications components accurately.

Five additional claims use the apparatus to complement the basic autonomous attitude determination function.

- A single aperture and scan mirror enable a compact optical design.
- An internal optical alignment technique is implemented using an alignment beam with the common mosaic sensor.
- An image stabilization technique can be included using the existing apparatus.
- The same apparatus can be used to sense the sun's location.
- The Kalman filter provides an accurate estimate of the attitude given the input measurements from the sensors.

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The advantages of this new approach include avoided cost and reduced volume by eliminating two functions that were included in past satellite systems.

- The GPS navigation measurements for low-altitude satellites replace the need for ground tracking stations to track low-altitude satellites continuously. Ground tracking and updating the orbital elements is an expensive operational function.
- The combination of local-vertical measurement by horizon scanning along with the GPS navigation measurement provides an attitude reference with respect to latitude and longitude that eliminates the need for a star tracker. Star trackers are expensive sensors and require updating star tables as part of operational procedures.

Attitude determination in an earth-pointing frame can be visualized as a combination of gyrocompassing, earth horizon sensing, and sensing the sun's center. Gyrocompassing consists of sensing the out-of-orbit plane angular velocity as a measure of azimuth in conjunction with the earth's horizon sensors, which yield the local vertical. In addition to the horizon measurements, the sun measurement is used periodically to calibrate for gyro drift. The GPS receiver determines the ephemerides of the earth and sun as seen by the satellite, and allows conversion of the attitude coordinates from the earth pointing frame to an inertial frame. Also, the GPS receiver allows estimating the satellite's orbital angular velocity that, in conjunction with the gyrocompassing, produces an additional estimate of azimuth.

The Kalman filter provides a systematic procedure for combining all this information continuously and in an optimal fashion to estimate the satellite attitude both in earth pointing and in inertial frames. The Kalman filter also effectively and accurately computes the direction to the sun's center by combining GPS-provided ephemerides for the apparent diameter of the sun with sightings of the sun's edge.

The result of this new approach using fewer components packaged in a more compact arrangement and not requiring ground station support is satellite attitude estimates of sufficient quality for use either in earth surveillance or in inertial pointing (e.g., of a satellite laser beam to another satellite). In a surveillance satellite, the equipment referred to above is already present: the gyroscope package would be provided for telescope line-of-sight inertial, and the surveillance telescope and optics could be modified for the sun and earth sensing. An expensive and bulky star tracker is not required.

Biographies

William M. Johnson is a Principal Member of the Technical Staff in the Electronic Sensors and Systems Department at Draper. He received a BS in engineering science from Case Institute of Technology and an MS in mechanical engineering from MIT. Since joining Draper in 1963, Mr. Johnson has designed ultraviolet radiometers for two Air Force experimental satellite flights; he has been a flight test engineer on FAA test aircraft with the Draper Inertial Locator Experiment, designed pointer/tracker systems for high-energy lasers for the Army and Air Force SDI program, and has been a systems/test engineer for the GPS shuttle experiment flown in 1996. He is currently working on the Kistler program for a two-stage reusable commercial launch vehicle. Mr. Johnson has received several recognition awards from Draper, and holds numerous patent awards in the area of precision pointing/tracking.

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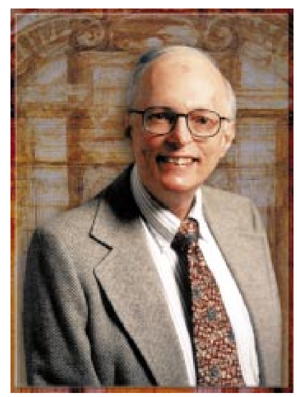

Howard Musoff is a Principal Member of the Technical Staff in the Guidance Technology Department at Draper. He received a BEE from the City College of New York (CUNY) in 1960, an MS in electrical engineering from Northeastern University in 1966, and an ScD in instrumentation from MIT in 1979. Dr. Musoff has been employed at Draper since 1960. He performs analyses for calibration and testing of inertial navigation systems. He is also coholder of a U.S. patent for an “Inertial Navigation System with Automatic Redundancy and Dynamic Compensation of Gyroscope Drift Error” and was cowinner of the Charles Stark Draper Laboratory award for best patent in 1993.

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