Automated Celestial Systems for Attitude & Position Determination

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Isn’t GPS Enough?

- Much work now ongoing in DoD to mitigate effects of GPS denial (primarily by jamming)
  - GPS enhancements (AJ, etc.)
  - Complimentary technology
  - Independent technology (alternatives)

- Navy policy requires each vehicle to have two *independent* means of navigation
  - recently reiterated in policy letter
What About INS as a GPS Alternative?

- Inertial navigation systems (INS) are now common on aircraft and ships, both military and commercial
- A form of precise, automated dead reckoning
- Accuracy (position drift) varies widely
- Must be periodically aligned with an external reference system:
  - GPS
  - LORAN
  - Celestial
Advantages of Celestial Nav

- Absolute – self-calibrating
- World-wide
- Passive, self-contained
- Nav aids (stars) need no maintenance
- Widespread use and experience
Automating the Celestial Observations

Compared to manual methods, automated systems can provide

- Better accuracy
- Higher data rate
- Determination of platform attitude
- Direct input into INS
Celestial Attitude and Position Determination — Principles

2 or more stars ⇒ 3-axis attitude in inertial space
+ vertical ⇒ attitude wrt horizon
+ time ⇒ latitude and longitude

...assuming
star catalog data + formulas for Earth orientation as a function of time
Automated Star Trackers

Used in

- Missile guidance
  - Snark, Polaris, Poseidon, Trident, MX
- Satellite attitude determination
  - XTE, SWAS, STEX, DS-1, WIRE, etc.
- Aircraft navigation
  - SR-71, RC-135, B-2
- Space Shuttle guidance
- Planetary exploration spacecraft
Star Tracker Technology

● Old Technology
  • Gimbaled
  • Single-star observations
  • Photomultiplier tube or similar detectors
  • Programmed observations based on EP & attitude

● New Technology
  • Strapdown
  • Multiple-star observations
  • CCD detectors
  • Automatic star pattern recognition
New vs. old technologies

- ~1/3 weight, size, and power
- $3 \times MTBF$
- Higher data rates

...but, newest technologies mostly confined to space applications so far
Star Tracker Technology (cont.)

Observing in the far red / near IR

- Can observe in daytime — sky dark
- Atmosphere more transparent
- ~3 times more bright stars
- CCD quantum efficiency max in red

![Star Sight Probability Graph](attachment:image.png)

- % Probability
- Height (1000 ft)
- Star Sight Probability
Star Tracker Examples

Example 1: B2

- Legacy system from Snark, SR-71
- 150-lb unit in left wing, 10-inch window
- View up to 45° off vertical: out of 52 star catalog, 4-6 stars visible at any given time
- Cassegrain telescope on gimbaled platform
  - 2-inch aperture, 40 arcsec FOV, PMT detector
- Programmed sequence of observations, several per minute
- Azimuth and elevation data back to INS
Example 2: Northrop OWLS

- Strapdown system (non-gimbaled)
- CCD detector, R band ($\lambda$ 0.6-0.8 $\mu$m)
- Three simultaneous $3^\circ$ fields of view
  - holographic lens
- Stars to magnitude 5 in daylight at sea level
- 1 arcsecond (5 $\mu$rad) precision
- 2-axis attitude data back to INS
Star Tracker Examples (cont.)

Example 3: Lockheed Martin AST-201

- Space qualified
- CCD detector, visual band
- 8.8° field of view, multiple stars
- Stars to magnitude 7, depending on rotation
- 0.7 to 2 arcsecond (3-10 µrad) precision
- Star photons in → orientation angles out
  self-contained star catalog, recognition software
Determination of the Vertical

• An easy problem from stationary locations
  • can use precision tiltmeters

• A hard problem from moving vehicles!
  • Motion-related accelerations not separable from gravitational acceleration
  • Generally, must use INS vertical (from NAVSSI?)
  • Other possibilities:
    – horizon sensor
    – atmospheric refraction
    – observe artificial satellites against star background
Conclusions

- Existing DoD astro-inertial systems demonstrate feasibility of accurate autonomous navigation without GPS.
- New technology star trackers show promise of wider application possibilities for surface/air navigation at lower cost.
- Still TBD: detailed price and performance expectations for new systems.