Modulating Retro-reflectors for Space Tracking, Acquisition and Ranging using Multiple Quantum Well Technology

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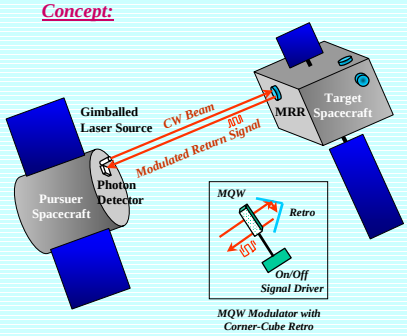
Objective

Provide a compact, lightweight, low power method to acquire and track multiple spacecraft (s/c) at long ranges (multiple kilometers).

Approach

Use frequency-tagged corner-cube Multiple Quantum Well (MQW) retro-modulators to provide relative position and orientation or acquisition, tracking and line-of-sight positioning and demonstrating technique in the NRL Robotics Laboratory.

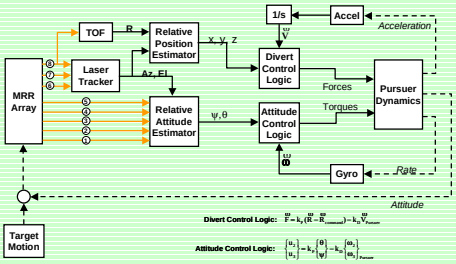
Concept:



MQW Modulator with Corner-Cube Retro

CONCEPT:[1] Pursuer illuminates target MRR with continuous wave laser beam and captures the reflected modulated light on the photodetector. The modulation sequence contains information about the target spacecraft such as *identification* and *orientation*. *Range* and *relative position* can also be obtained from time-of-flight measurements and laser gimbal angles.

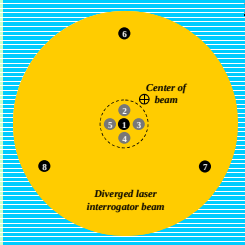
Pursuer Navigation and Control:



Divert Control Logic: $\vec{F} = k_v(\vec{R} - \vec{R}_{commanded}) - k_m \vec{v}_{Pursuer}$

Attitude Control Logic: $\begin{bmatrix} u_\psi \\ u_\theta \end{bmatrix} = -k_p \begin{bmatrix} \theta \\ \psi \end{bmatrix} - k_D \begin{bmatrix} \omega_\psi \\ \omega_\theta \end{bmatrix}_{Pursuer}$

Determination of Target Attitude:



Fundamental Signals

$S_i = S_0 - a\alpha_i$

S_i = signal return from ith MRR
α_i = laser angle to ith MRR boresight
β = fixed 20° cant angle of MRRs 2-5

Relative Yaw & Pitch Estimation

If $S_3 > S_5$: $\psi = \frac{1}{2}\frac{S_3 - S_5}{S_1 - S_5}\beta$

else : $\psi = -\frac{1}{2}\frac{S_5 - S_3}{S_1 - S_3}\beta$

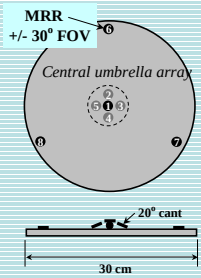
If $S_2 > S_4$: $\theta = \frac{1}{2}\frac{S_2 - S_4}{S_1 - S_4}\beta$

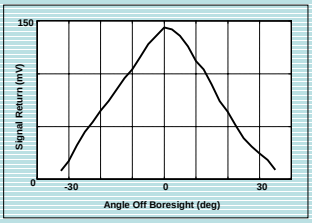
else : $\theta = -\frac{1}{2}\frac{S_4 - S_2}{S_1 - S_2}\beta$

MRRs 1-5 -> relative attitude determination

MRRs 6-8 -> relative position determination

MRR Array For Target Pose:





Sensitivity of MRR to laser beam angle

SEQUENCE:

1. Laser beam divergence illuminates array; 2. Laser gimbal motion equalizes signal returns of MRRs 6-8 to provide relative position vector; 3. Signal returns of MRRs 1-5 provide two-axis relative target attitude (pitch, yaw).

Combined with pulse TOF measurement, sensor provides relative navigation of ~1 cm in position and~0.3 deg in attitude

Eight Element Retromodulator Array is shown. Each unit is driven with a different code for device discrimination.

Inter-Spacecraft Geometry

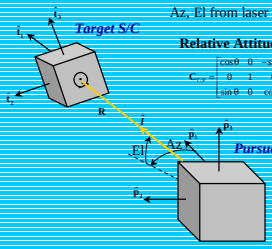
Relative Position Vector:

$\vec{R} = R(\cos El \cos Az\, \vec{p}_1 + \cos El \sin Az\, \vec{p}_2 + \sin El\, \vec{p}_3)$

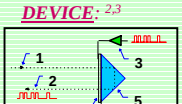
Az, El from laser gimbal angles

Relative Attitude (Pointing) Matrix:

$$C_{T \to P} = \begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{bmatrix} \begin{bmatrix} \cos\psi & \sin\psi & 0 \\ -\sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

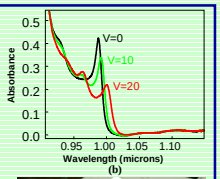


DEVICE: [2,3]

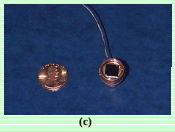


1. Interrogation beam; 2. Modulated beam; 3. Electronic driver; 4. Transmissive MQW modulator; 5. Solid retro-reflector

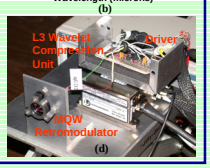
(a)



(b)

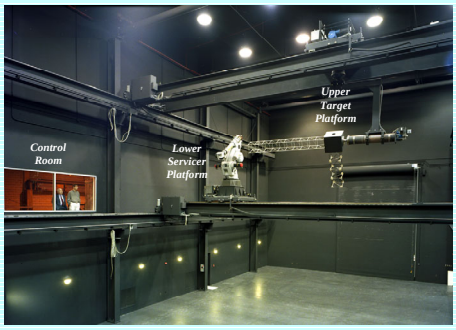


(c)

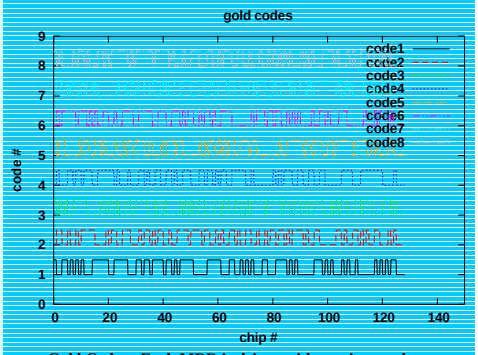


(d)

CORNER CUBE MQW RETROMODULATOR: Concept is shown above in (a). When a voltage is applied to the shutter, the absorbance wavelength is shifted as shown in (b) enabling ON-OFF-KEYING; The MQW in these experiments is on the order of 6.3 mm in diameter as shown in c. A mounted unit is shown in (d) where it is driven by a wavelet compression unit and an impedance matching circuit. The mounted retromodulator is 10 grams and required 130 mW to support 4 Mbps, 30 fps of color video across the link.



***Dynamic Motion Simulator Laboratory*: National testbed for testing and verification of autonomous rendezvous and capture technologies. This dual platform facility offers 6 degrees of freedom per platform. Space environmental conditions can be programmed into the simulations. Facility workspace dimensions:30 m x 13 m x 5 m.**



Gold Codes: Each MRR is driven with a unique code which is detected decoded, and translated to a level to cue the tracking and acquisition algorithms. The devices are driven at 1 Mbps and required about 80 mW per unit with a per mounted unit mass of 10 grams.

References:

1. N. G. Creamer, G. C. Gilbreath, T. J. Meehan, T.J., M.F. Stell, M. J. Vilcheck, and W. S. Rabinovich, "Multiple Quantum Well Retromodulators for Spacecraft-To-Spacecraft Laser Interrogation, Communication, and Navigation," 15th Annual AIAA/USU Conference on Small Satellites, Logan, UT, August 13-15, 2001.
2. G.C. Gilbreath, S.R. Bowman, W.S. Rabinovich, C.H. Merk, H.E. Senasack, "Modulating Retroreflector Using Multiple Quantum Well Technology", U.S. Patent No. 6,154,299, awarded November, 2000.
3. G. C. Gilbreath, W. S. Rabinovich, T. J. Meehan, M. J. Vilcheck, R. Mahon, Ray Burris, M. Ferraro, I. Sokolsky, J. A. Vasquez, C. S. Bovais, K. Cochrell, K.C. Goins, R. Barbehenn, D. S. Katzer, K. Ikossi-Anastasiou, and Marcos J. Montes, "Large Aperture Multiple Quantum Well Modulating Retroreflector for Free Space Optical Data Transfer on Unmanned Aerial Vehicles", Opt.Eng., **40** (7), pp. 1348-1356, 2001.