SINGLE AXIS POINTING BY MEANS OF TWO REACTION WHEELS

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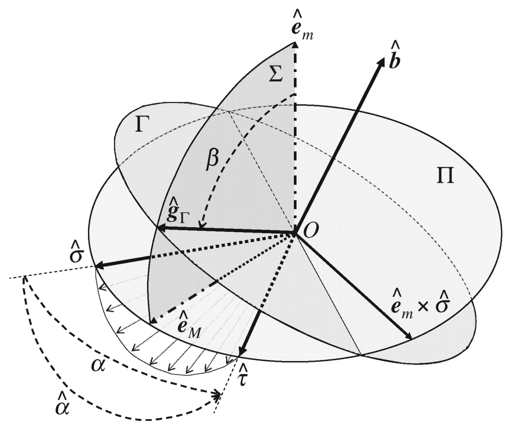
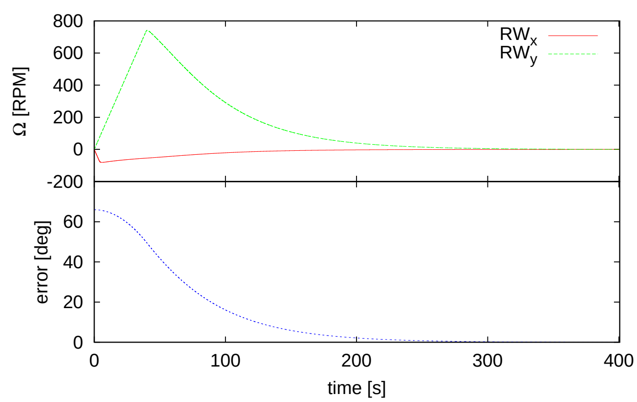
The paper proposes a novel approach for single-axis pointing by using only two reaction wheels (RW), by means of a simple yet effective wheel rate command. This maneuver technique can be used for aiming the line-of-sight of a sensor towards a target direction or solar panels towards the Sun after failure of wheel for a non-redundant control system hardware or in the case of multiple failures for redundant systems. Examples of this kind of situation are the Far Ultraviolet Spectroscopic Explorer (FUSE) and Kepler space telescope, that both suffered from failures that left only two wheels available for maneuvers. Failure of mechanical actuators is also expected to potentially affect low-budget space missions based on small-size low-cost spacecraft (nano-, pico-, and cube-sat families). Among many other papers on the subject of attitude control with two effectors, Tsiotras&Longuski presented a methodology for constructing feedback control laws for the attitude stabilization about the symmetry axis in [1]. Kim & Kim [2] considered the problem of spin stabilization of a spacecraft about a specified inertial axis using two reaction wheels. They exploited the $z-w$ parametrization introduced by Tsiotras [3] to derive a feedback control law that globally and asymptotically stabilizes the spacecraft about a revolving motion along a specified inertial axis. A singular controller was proposed by Horri for the 3-axis attitude stabilization of a zero total angular momentum satellite, based on a Rodriguez parametrization of the attitude [4] or on a quaternion attitude parametrization [5]. Yoon &Tsiotras [6] considered a spacecraft equipped with a single VSCMG, proposing an LQR control law to locally stabilize the spacecraft angular velocity, while also controlling a given spacecraft body-axis in inertial space.

The approach here proposed allows for a computationally inexpensive control technique that directly stems from the kinematic planning scheme of [7], representing its practical, dynamic implementation, under the assumption of zero overall angular momentum. An ideal admissible rotation eigenaxis $\hat{\mathbf{g}}_\Gamma$, that allows for aiming a body-fixed axis $\hat{\sigma}$ towards a prescribed direction $\hat{\tau}$ when the admissible rotation axis is constrained to lie on a plane perpendicular to the torqueless direction $\hat{\mathbf{b}}$, is identified. The eigenaxis $\hat{\mathbf{g}}_\Gamma$ is chosen at the intersection of the planes Γ and Σ, where Γ is perpendicular to $\hat{\mathbf{b}}$ (identified in the present application by the plane that contains the spin axis of the two active RW's), and Σ contains all the axes that allows for performing the required alignment of $\hat{\sigma}$ over $\hat{\tau}$ [Fig. 1(a)]. The amplitude $\hat{\alpha}$ of the rotation around $\hat{\mathbf{g}}_\Gamma$ is determined analytically from the geometry of the problem [7]. Assuming that the wheel 3 fails, and under the zero-momentum hypothesis, $\mathbf{h} = \mathbf{I}\omega + I_{sw}(\Omega_1^r \hat{\mathbf{e}}_1 + \Omega_2^r \hat{\mathbf{e}}_2) = 0$, it is possible to derive a wheel control torque command, $u_i = k_\omega(\Omega_i^d - \Omega_i^r)$, $i = 1,2$, that tracks the desired wheel spin rate $\Omega_i^d = -\mathbf{I}\omega^d \cdot \hat{\mathbf{e}}_i / I_{sw} = -(J_i/I_{sw})\omega_i^d$, where $\omega^d = (\Omega_1^d, \Omega_2^d, 0)^T = k_\alpha \hat{\alpha} \hat{\mathbf{g}}_\Gamma$ is an admissible spacecraft rotation rate. This implements the kinematic planning scheme at a dynamic level. The time history of wheel angular rates and pointing error are reported in Fig. 1(b) for a test case dealing a with a 320 kg mini-satellite used as a reference spacecraft in [5] and adopted here for comparison purposes.

In the final paper, the derivation of the nominal control law for $\mathbf{h} = \mathbf{0}$ will be discussed in more detail, with a proof of stability based on a Lyapunov candidate approach that results into bounds for the control gains that guarantee asymptotic convergence of $\hat{\sigma}$ over $\hat{\tau}$. Convergence towards the prescribed axis alignment will then be analyzed by means of numerical simulation. The effect of a non-zero residual angular momentum on pointing error and wheel misalignment with respect to principal axes will also be investigated, highlighting pointing precision performance limitations. The merits of the approach in terms of reduced CPU effort will also be underlined, a relevant feature when dealing with the limited computational power of typical hardware on small-size spacecraft.



(a)



(b)

Figure 1. a) Kinematic planning scheme; b) Pointing error during an alignment maneuver.

1. References

[1] Tsiotras, P. and Longuski, J. M. "Spin-axis stabilization of symmetric spacecraft with two control torques." Systems & Control Letters, Vol. 23, No. 6, pp. 395–402, 1994.

[2] Kim, S. and Kim, Y. "Spin-Axis Stabilization of a Rigid Spacecraft Using Two Reaction Wheels." Journal of Guidance, Control, and Dynamics, Vol. 24, No. 5, pp. 1046–1049, Sep. 2001.

[3] Tsiotras, P., Corless, M., and Longuski, M. "A Novel Approach to the Attitude Control of Axisymmetric Spacecraft." Automatica, Vol. 31, No. 8, pp. 1099–1112, 1995.

[4] Horri, N. and Hodgart, S. "Attitude stabilization of an underactuated satellite using two wheels." "Aerospace Conference, 2003. Proceedings. 2003 IEEE," Vol. 6, pp. 2629–2635. March 2003.

[5] Horri, N. M. and Palmer, P. "Practical Implementation of Attitude-Control Algorithms for an Underactuated Satellite." Journal of Guidance, Control, and Dynamics, Vol. 35, No. 1, pp. 40–45, Jan. 2012.

[6] Yoon, H. and Tsiotras, P. "Spacecraft line-of-sight control using a single variable-speed control moment gyro." AIAA Journal of Guidance Control and Dynamics, Vol. 29, No. 6, p. 1295, 2006.

[7] Avanzini, G. and Giulietti, F. "Constrained Slews for Single-Axis Pointing." Journal of Guidance, Control, and Dynamics, Vol. 31, No. 6, pp. 1813–1816, Nov.-Dec. 2008.