Deimos Experience, Insight and Perspective on Space FDIR

Andrés Marcos, Luis F. Peñín
Deimos Space S.L.U.

The state-of-practice to diagnose guidance & control (G&C) faults and obtain full flight envelope protection at all times is to provide high levels of hardware redundancy in order to perform coherency tests and ensure sufficient available control action. This hardware-based redundancy approach to fault detection & diagnosis (FDD) and fault tolerant control (FTC) is nowadays the standard industrial practice and fits also into current industrial certification processes while ensuring the highest level of safety standards.

Unfortunately, for space systems, the usual implementation constraints found in commercial and military aviation, such as computation load and complexity, are also encountered albeit to a greater degree due to the more limited weight and computational processing capabilities. These more restrictive limitations arise from the expensive cost, around €10,000 to €20,000, for putting one kilogram of payload in space and by the lengthier testing and validation process required to classify any design as space-ready, which results in a de facto decade-long technological delay. The weight limitation directly affects the system decisions related to hardware redundancy while the processing limitation affects those decisions related to the choice of the on-board FTC and FDD techniques.

In addressing these limitations space systems typically use: (i) geometric solutions, such as the 4-to-3 inertial measurement units (IMU) configuration found in many satellite systems where four individual IMUs are positioned to provide redundant measurements in three axes, or (ii) a complete hardware duplication solution when the criticality of the system is high. An example of the latter is the use of a two (fully independent) thruster-sets in failover configuration, where the primary set is active until an abnormality is detected at which time the secondary set is activated and the first is switched off – note that in this case, only a fault detection scheme might be required which helps address the processing limitation. For other space systems such as winged atmospheric re-entry vehicles (e.g. Space Shuttle, X33, X38…) which have aircraft-like configurations more redundant control actuation architectures can be used–capsules, like the Apollo or Soyuz are similar but, again, with more limited weight capabilities compounded by the more restrictive aerodynamic and controllability characteristics resulting from their lower Lift-to-Drag ratios.

The space systems' stringent system hardware redundancy limitation found in space systems has a positive influence on the consideration of advanced (model-based) FDIR techniques, which provide redundancy without significant weight increase (analytical redundancy). Despite this, the processing limitation as well as implementation, performance, reliability and certification issues have all slowed the use of these techniques in space. Nevertheless, there is a growing need to move towards greater space system autonomy which requires 'intelligent' technology for self-diagnosis and self-healing.

This need is driven by the more challenging requirements of future space missions, examples of which are the lunar/mars robot and human campaigns (such as the very successful NASA Mars Exploration Mission or ESA Exomars and Mars Sample Return, both currently in development), and the in-the-drawing-board science missions involving multi-craft formation flying, Near Earth Objects (NEO) or deep space exploration in general (e.g. ESA Proba-3 and the twelve-spacecraft Cross-scale concept, or the joint NASA/ESA LISA mission).

Two main technological directions are envisioned by Deimos as a future R&D plan:

- From a long-term perspective, systems that integrate the monitoring of the principal external and internal upset conditions and are capable of proposing and implementing the adequate corrective actions will be fundamental for autonomous space systems. Health management systems (HM) represent such a future system but its realization requires maturation of two other axes of technology as it has been mentioned before: FDD and FTC.
- From a shorter-term perspective, and looking at the holistic technology development cycle, certification and qualification processes are key enablers in facilitating the rapid introduction of innovative technologies. Indeed, certification is typically the short-stopper in the implementation of the most advanced control and diagnosis developments. Advanced FTC, and to a lesser extend advanced FDD designs, have not been considered up to now in a coherent manner from a certification stand-point and this has precluded their widespread use (similar, if not the same, reason applies to advanced guidance and control technologies).