Abstract

This dissertation investigates attitude and pointing challenges in next-generation Earth-observation radar missions, in which scientific objectives are closely tied to accurate design, control, and knowledge of the observation geometry. Particular focus is devoted to two missions: WIVERN (WInd VElocity Radar Nephoscope), selected by ESA as Earth Explorer 11, whose observational concept relies on Doppler and reflectivity measurements acquired at multiple azimuth angles to provide global observations of winds within clouds and precipitation; and INCUS (INvestigation of Convective UpdraftS), a NASA three-spacecraft constellation designed to investigate tropical convective storms through time-differenced radar measurements with nominal separations of 30, 90, and 120 seconds.

A first contribution of the dissertation is the development of a rigid multibody dynamics and control model of a spacecraft carrying a rapidly rotating antenna reflector, inspired by the configuration and operating conditions of the WIVERN mission. The study addresses the balancing of the rotating payload and analyzes the effects of residual static and dynamic imbalances, whose induced disturbances are counteracted by a sliding mode controller designed for the combined control of the spacecraft attitude and antenna spin rate. The resulting pointing performance and control effort are assessed in a simulated nominal operating scenario. The model also serves as the core dynamical block of a complete simulator that includes a determination block developed within a collaborative framework. This simulation chain supports the verification of knowledge requirements on the non-geophysical contribution to the line-of-sight Doppler velocity, which is essential for accurate LOS Doppler retrievals.

A second contribution concerns the derivation of pointing profiles for spacecraft missions requiring continuous observation of an Earth-fixed ground path, with application to the INCUS observation strategy. A pitch–roll–yaw attitude param-

eterization is adopted to align each spacecraft with a common reference ground path while accounting for mission-specific scientific and instrumental constraints. In particular, a fixed-pitch strategy and time-varying roll profiles are investigated for ground-path tracking, while an additional yaw rotation is introduced to achieve the desired cross-track alignment of the radar footprints. The yaw profile is determined through a numerical search procedure, and a complementary analytical formulation of the footprint-alignment problem is also explored. Sensitivity analyses are then carried out to assess the effects of orbital altitude, inclination, and spacecraft position-knowledge errors on the pointing profiles and footprint placement.

The final part of the thesis extends the INCUS pointing framework to avoidance maneuvers, in which the nominal reference ground path is locally modified to avoid direct pointing toward ground RF systems while preserving science operations. The problem is addressed using two optimization-based approaches. The first is formulated in attitude space and generates a time series of a selected pointing vector, whereas the second is formulated in ground-path space and directly generates a modified Earth-fixed path traced by the same pointing vector. In both cases, the optimization problem is solved using a gradient-based sequential quadratic programming method. The first approach provides considerable flexibility but leads to a large number of design variables and may generate non-smooth solutions. These may require a posteriori polynomial approximation, which is not guaranteed to preserve the optimality or feasibility of the original discrete solution. These limitations motivated the second approach, which incorporates smoothness directly into the optimization problem by parameterizing the ground path through a fixed-order multi-interval Chebyshev representation combined with a receding-horizon strategy. In both approaches, the avoidance constraint is explicitly enforced, while mission-specific soft constraints are incorporated through the objective function. Off-nadir minimization is included directly through a dedicated objective-function term, whereas footprint-overlap and alignment preservation are addressed more indirectly through smoothness-related penalties. This indirect connection is analyzed in detail for the Chebyshev-based formulation.

Overall, the thesis provides a set of dynamical models, guidance strategies, control laws, and optimization tools for the analysis and design of Earth-observation radar missions with demanding pointing and attitude requirements. The results contribute to the modeling of rotating-payload spacecraft, the generation of ground-path pointing profiles for constellation missions, and the formulation of avoidance

strategies aimed at maintaining science observations in the presence of ground-based RF systems.