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RELATIVE ATTITUDE ESTIMATION VIA RADIO FREQUENCY LINKS - FEASIBILITY STUDY BASED ON HIGH-FIDELITY CO-SIMULATION

Abstract

Relative attitude control between satellites or each satellite and a ground station is of recent interest, especially for nano- and micro-satellite flying in formation. Instead of absolute attitude determination via solar or star sensors in an intertially-fixed coordinate system, modern communication subsystems utilizing multiple antennas could directly realize relative attitude determination via Direction-of-Arrival (DOA) estimation on the radio-frequency (RF) links. This offers a high potential to reduce the necessity for dedicated attitude determination sensors, and hence help to save the scarce resources in nano- and micro-satellite missions.

This work proposes a method for RF link-based relative attitude determination and evaluates it using a high-fidelity co-simulation framework. The mission modelling is performed in AGI System Tool Kit. Resulting mission-level parameters like transmit frequency, gain, noise, receiver antenna array properties, and Doppler shift are returned. In particular, highly-accurate simulations of the propagation paths between individual antenna elements at spacecraft and/or ground stations, in fractions of the wavelengths of interest, are obtained. These mission parameters are then used by a subsequent RF simulation implemented in Matlab/Simulink. Here the signal path and its propagation from transmitter to each receiving antenna element of the satellite's antenna array is simulated in terms of time-domain equivalent complex baseband signals, including all effects such as free space path loss, Doppler shift, receiver thermal noise, and the DOA-dependent phase shift between the individual antenna elements. Using the model-based implementation in Simulink then allows to evaluate different DOA estimation techniques such as Bartlett Beamforming and MUSIC. A large selection of parameters such as the modulation of the Tx signals as well as the number of snapshots used for DOA estimation can be varied and their influence on the performance of the DOA simulation studied.

Key contributions of this work are the development of a new simulation framework to perform high-fidelity simulation of mission dependent RF links, and a subsequent thorough feasibility study of RF-link-based relative attitude determination. Parametric studies for several use cases, utilizing the high degree of automation and modularity of the simulation framework, are included. Based on an analysis of different mission scenarios involving different links, antenna configurations and signal properties, as well as different DOA estimation algorithms, the feasibility for RF-link-based relative attitude determination for nano- and micro-satellites is evaluated and the achievable performance discussed. In addition, the impact

on the satellite design such as antenna positioning, usable communication signals and frequency bands is addressed.