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Digital Twin Analysis for Multipath Characterization of Robot-Based GNSS Code Phase Variation Calibration Sites

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Satellite navigation has been an important driving force of many modern technological advancements. From surveying to positioning applications, the Global Navigation Satellite System (GNSS) remains a key enabler. The obtainable quality of GNSS measurements is defined by the positioning error budget. While strong improvements can be achieved for instance, in the satellite or propagation error estimation (through use of dual frequency measurements or through use of augmentation systems), the errors generated at or close to the antenna are more difficult to estimate and counteract. Being the first element in the GNSS receiving chain, antennas significantly influence the quality of received signals.

While considerable work has been done in the last years to precisely estimate carrier phase related antenna errors, also called phase center variation (PCV) errors; the effect of the antenna on the code measurement (i.e. the analysis of code phase variations- CPV) has received less attention.However, CPV effects becomes very relevant in specific applications, like avionics or time/frequency transfer. Precise CPV determination and subsequent compensation of its related errors could be guaranteed through accurate antenna calibration. As such, good calibration methods should be further investigated and possibly standardized.

Currently, CPV estimation, similarly to PCV, can performed either in an anechoic chamber or through field observations using a robot. However, it has been observed that CPV estimated using each of these approaches tend to show mismatches. These discrepancies are thought to be related to sources such as high multipath-induced code noise and impact of receiver settings in the robot calibration method. Consequently, characterization of CPV remains a challenging task largely due to a general incomplete understanding of the complex multipath-antenna- receiver interactions. In terms of accuracy and repeatability, the levels needed in a standardized calibration procedure of CPV has not yet been met.

In this work, as a first step towards higher precision and repeatable CPV calibration, focus is placed on undertaking deeper investigation into multipath-antenna interactions and examining the contribution of multipath-induced error to the overall code-noise budget. To do this, the multipath conditions in a robot calibration site is studied using a multipath probe. This probe is an in-house developed antenna with reconfigurable electromagnetic properties and has the ability to mimic the responses of different GNSS antennas to multipath. These responses are quantified using the so-called multipath suppression capabilities indicators (MPSI) discussed by authors in previous works. This allows for substitutive characterization which is based on a proven premise that different antennas having similar MPSI (for a given spatial direction) exhibit comparable multipath suppression, i.e. receive the same amount of multipath when placed in the same scenario. Furthermore, we shall discuss the potential of using a hybrid (digital twin) simulative approach for multipath characterization. Here, anechoic chamber measurements of a given antenna are integrated in electromagnetic simulations of its anticipated surrounding physical environment. With this technique, it is possible to accurately predict and analyze sources of multipath conditions that such antenna will experience in situ. A fusion of the multipath probe's MPSI reconfigurability and the

hybrid simulative method presents a flexible but powerful tool to better understand, from the antenna viewpoint, the amount of multipath conditions on robot calibration measurements. We shall demonstrate the efficacy of this characterization technique by comparing simulated installed performance with experimental field measurements.