Phase-Based Wireless Localization for Human Motion and Pose Estimation at Millimeter- and Submillimeter-Wave Frequencies and Beyond

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Abstract

Gait analysis traditionally relies on marker-based optical motion capture (OMC) systems, which offer high precision but suffer from limitations such as marker dependency and strict visibility requirements. Inertial measurement unit (IMU) systems provide a wearable alternative; however, they are prone to integration drift and require precise calibration. Markerless optical motion capture technologies, show great promise but still face challenges regarding accuracy in complex movements and clinical validation. Wireless localization systems aim to overcome these limitations by providing six-dimensional (6D) position and orientation data without optical constraints. Conventional approaches—such as Received Signal Strength (RSS), Time of Arrival (TOA), and Round-Trip Time of Flight (RTOF)—estimate distances between transmitters and receivers based on signal power or propagation time. However, these methods typically encounter limitations in accuracy due to multipath effects, clock synchronization issues, and environmental variability. To address these challenges, phase-based wireless localization at millimeter- and submillimeter-wave frequencies offers a promising alternative.

In this presentation, the basic principles of phase-based wireless localization, particularly holographic localization using a spatial optimal filter and the Holographic Extended Kalman Filter (HEKF), and their unique features will be explained. These methods enable robust, synchronization-free, and highly precise position estimation. Furthermore, it will be demonstrated how the selected frequency and aperture size influence localization accuracy, and why millimeter-wave and terahertz (THz) signals are particularly well suited for this type of radio localization, outperforming broadband methods such as UWB. Finally, the high precision of phase-based positioning systems, achieving millimeter-level accuracy, is validated through a specific implementation and application example in human pose and movement measurement.