Position Estimation with Integrated UWB/MIMU Data in the Context of 3D Analysis of Human Movement

Vinish Yogesh[1,2], Jaap H. Buurke[1,2], Bert-Jan F. van Beijnum[2], **Chris T.M. Baten**[1,2]
[1]Department of Rehabilitation Engineering, Roessingh Research and Development, Enschede, The Netherlands
[2]Department of Biomedical Signals and System, University of Twente, Enschede, The Netherlands
Email: c.baten@rrd.nl

Summary

This study proposes and validates an Extended Kalman Filter (EKF)-based data fusion method applied to data of an on-body swarm of Ultrawideband (UWB) and Magnetic Inertial Measurement Unit (MIMU), integrated in custom UMIMU sensors, for 3D ambulatory human movement (3D AHM). Experimental validation using MIMU sensors and simulated UWB data shows an 8.3 cm mean position error, better than most prior UWB/MIMU methods designed for pedestrian navigation. While the approach enhances accuracy, further improvements are needed for clinical application. This study uniquely tailors and validates UWB/MIMU fusion for 3D AHM, addressing a gap in existing research.

Introduction

The integration of UWB and MIMU sensors holds great potential for accurate position estimation. UWB provides drift-free absolute position estimates but suffers in Non-Line-of-Sight conditions [1], while MIMU offers relative position tracking but accumulates 'integration drift' errors over time. Although their complementary strengths facilitate improved accuracy through data fusion techniques [2], integrated UWB/MIMU systems have not been widely adopted for ambulatory 3D AHM due to limited accuracy and stability. Also, current methods in literature combining these sensors are not specifically tailored and validated for 3D AHM applications; they only have been widely investigated for pedestrian navigation applications [3]. This study examines an EKF data fusion approach, in typical 3D AHM conditions.

Methods

This research utilizes the MIMU sensors and simulated UWB measurement from an optical motion capture system to develop and validate the data fusion approach. UWB distances between all sensors in the network were estimated in a swarm topology, for which distances between all sensor nodes in the network were measured. The positions were estimated from simulated UWB distance measures through trilateration with three known fixed positions. Data fusion is performed through a loosely coupled EKF, where high-frequency MIMU data aids prediction based on Newton's equations of motion, and lower-frequency UWB position updates refine the estimates. An additional position drift correction utilizing polynomial fitting on the integration drift error model is applied to further minimize integration errors.

To validate the EKF-based fusion, a controlled experiment was conducted using UMIMU sensors and a Vicon optical motion capture system, which provided position ground truth. This study reports validation results for MIMU data, recorded at 100 sps, combined with simulated UWB data derived from the Vicon data downsampled to 4 sps and with errors added artificially as observed in UMIMUs, being 0.5 cm bias and 5 cm Gaussian random error [4]. Synchronization was achieved by cross-correlation of acceleration estimates from MIMU and Vicon. The experiment involved random and cyclic hand-held sensor movements, with velocities and magnitudes matching those observed in typical 3D AHM scenarios.

Results and Discussion

The EKF 3D position estimates show a typical mean position estimation error of 8.3 cm, with a standard deviation of 4.32 cm. The mean absolute error per axis was 1.85 ± 1.45 cm, 6.00 ± 4.53 cm, and 3.95 ± 3.14 cm for the x, y, and z axes, respectively. An example of estimated position is in Figure 1. While the method improves accuracy, further enhancements are needed for clinical relevance in 3D AHM applications. Currently under study: improvement over the simple trilateration method for estimating the position measurement update and exploitation of the redundancy of the measured UWB distances within the network. Also, the performance with actual UWB/MIMU-data, including mitigation strategies for line-of-sight related distance measurement errors.

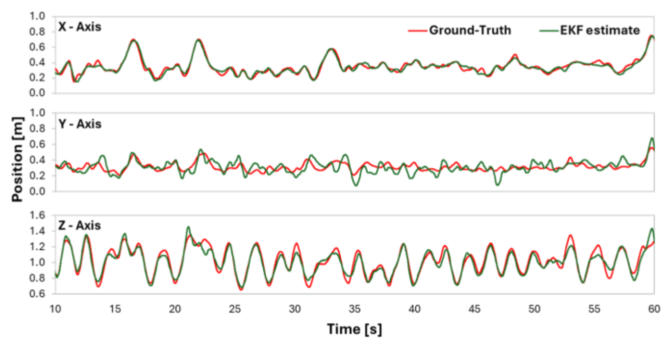

Figure 1: Position estimate from EKF plotted against ground truth.

Conclusion

This study presents an EKF-based data fusion method tailored, and validated, for 3D AHM-like conditions, which provides better accuracy than most prior studies integrating MIMU and UWB data, but needs further improvement.

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