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A Real-Time Deep Fusion Framework for RF Positioning Ensembles

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Abstract- In localization, ensemble solutions are commonly proposed to achieve better positioning accuracy than could be reached from any single constituent positioning algorithm alone [1, 2]. An ensemble of positioning solutions can be constructed by a fusion framework in either the sensor-input, the positioning algorithms, or the output-filter stages. Most previous fusion frameworks, however, usually rely on certain rigid, pre-programmed mechanisms to combine the outcomes from each ingredient positioning algorithm in the ensemble, resulting in unsatisfactory positioning performance particularly in the complex indoor contexts. Moreover, to our best knowledge, very few studies explored the execution efficiency characteristics of fusion frameworks in localization.

In this study we propose a new deep-learning based, real-time fusion framework to formulate flexible and expandable ensembles of RF localization solutions. Unlike previous ones, our framework adaptively adjusts not only the relative weights but also the data flow paths among various sensor inputs, positioning algorithms, as well as output filtering functions. During the sensor-input processing stage, various characteristics of each perceived RF signal source, including (but not limited to) the received signal strength (RSS) and round-trip delay time (RTT) etc., plus other sensor data including readings of the inertial measurement unit (IMU) onboard the devices under targeting (DUTs), are unified by extracting the information entropy to calculate their local information gains for further use. Each positioning algorithm module in the algorithmic stage then takes all or selected unified sensor inputs to obtain its location estimation with a corresponding confidence level respectively. In the final output stage, the outcomes from all positioning algorithm modules are going through a weighted combination of filtering functions to collectively determine one final position estimation. The data flows and the corresponding weights are subtly adjusted by a deep neural network (DNN) which is currently trained offline in a semi-supervised (unsupervised yet human-overridable) manner. Thus, our fusion framework adapts better to the complexity of indoor contexts and delivers stronger positioning performance.

To validate our proposed deep fusion framework in the real world, we designed and implemented a prototype of our deep fusion framework based on our previous work of Infrastructure-less positioning system [3], a 3-node, 10Gbit Ethernet-connected dual-Xeon server cluster running Google Kubernetes (*k8s*), and a complement of custom-built TurtuleBot3-based site-surveying robots for radio map construction. Within the initial build of our fusion framework prototype are two Wi-Fi positioning modules: A conventional K-Nearest Neighbors (*K*NN) and a much accurate classifier-regressor compound DNN (*ClassReg*), as well as two motion filter modules: A Kalman filter and a particle filter, respectively. According to preliminary experimental results of simultaneously positioning multiple Google Pixel 4 phones in *Ming-Da* Hall at National Taiwan University, our fusion framework achieves within 0.95m (3.1 ft.) and 0.99m (3.2 ft.) mean accuracies using the ensembles of straight *ClassReg* + Kalman filter and *ClassReg* + particle filter respectively, outperforming the baseline of *ClassReg* alone by 72% and 64% respectively, while retaining positioning latencies (excluding network transmission delays) no more than 0.14 seconds per each localization iteration.

Index terms: Fusion framework, deep learning, wireless positioning, ensemble models and filters.

References

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