Guoguo: Smartphone-based High-precision Indoor Location Ecosystem and Services

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ABSTRACT

Locating a smartphone at the centimeter-level has significant implication for potential indoor location services and applications compared with existing coarse-grained solutions. In this paper, we propose Guoguo ecosystem to fill the long-lasting gap of smartphone-based indoor localization. Guoguo consists of a constellation of low-complexity anchor network that enabling fine-grained localization by leveraging modulated acoustic beacons. We propose algorithms to improve its robustness, coverage, accuracy, and refresh rate. Our prototype shows centimeter-level localization accuracy and promising for real deployment and application. Such results are expected to make smartphone indoor localization available in our daily activities.

Keywords

Localization, Smartphone, Anchor Network, Acoustic

1. MOTIVATION

As one of the two key components of a mobile context (time and location), localization has been the subject of extensive works ranging from algorithms, models, supporting technologies, to systems and applications. Current coarse-grained (room-level or meter-level) localization results can hardly meet the requirements of indoor mobile applications. Indoor users can hardly navigate like using outdoor GPS services. Smartphone-based accurate indoor localization system has long been waited to transform indoor location based services (ILBS).

From a methodology point of view, time-of-arrival (TOA) based ranging approaches tyically achieve better localization accuracy and robustness than fingerprinting-based and other energy-based ranging approaches. The TOA ranging accuracy directly depends on the bandwidth (B) and the transmission speed (c) of the operating signal with a simple relationship shown as ($\sim c/B$). Using Bluetooth, WiFi or Cellular signals in current smartphone, the achievable TOA ranging resolution is larger than 100 meters due to their relative narrow bandwidth (MHz level). On the contrary, narrow band acoustic signal could achieve centimeter-level ranging accuracy due to its significant low transmission speed. Leveraging ubiquitous microphone sensors in a smartphone introduces a convenient and practical approach of localization, and expected to have high impact in the future ILBS and our daily activities.

2. CHALLENGES

Several major problems associated with the audible-band acoustic approach have not been conquered yet: the limited bandwidth of a microphone, strong attenuation of aerial acoustic signals, as well as various interferences in the audible band.

Unlike the radio-based localization approaches with dedicated operation band, using audible-band acoustic signal for localization suffers from strong in-band interference. Moreover, the low transmission speed of the acoustic signal causes problems of limited location update rate. Enabling accurate moving target localization and tracking, sufficient update rate should be achieved with limited measurements.

Although using acoustic signal suffers from various issues, the potential of centimeter-level localization accuracy motivates us to design better solutions to overcome its drawbacks.

3. RELATED WORK

As the key enabler for the future indoor location-based mobile services, significant efforts have been devoted to the indoor localization in both academia and industry in the past two decades. Current smartphone-based indoor localization could be summarized into following categories: RSS-based ranging using propagation attenuation of radio (WiFi, Cellular, and Bluetooth), fingerprinting-based matching using surround sound or radio profiles, and TOA-based ranging using acoustic signal. Different applications may have different requirements on the complexity, cost and resolution.

For fine-grained indoor localization application with high resolution requirement, TOA-based ranging is more promising. Authors [1, 2, 3, 5, 6] demonstrate the feasibility of using acoustic signal for indoor localization. However, these approaches suffer the problems of low update rate, small coverage, and limited scalability for multi-users. Guoguo, features non-assisted passive mode localization, has the features of longer operation distance, multi-user scalability, and reduced latency.

4. INITIAL RESULTS

The architecture of the Guoguo system is shown in Fig. 1. Several major components have been finished.

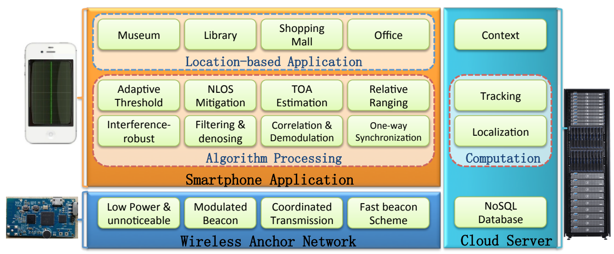

Figure 1: System Architecture.

Wireless Anchor Network: We design the anchor node from scratch and keep the BOM price as low as \$10 per node. The inter-node communication and synchronization have been implemented and achieved at a very high accurate level. The transmitted beacon signal has been tuned to be unnoticeable to humans with low-power and low-duty-cycle features. To enable passive sensing for multiple smartphone users, we design the transmission waveform with wide-band modulation, and a transmission scheme of the acoustic beacon that follows the high-density pseudo-codes. We propose a *symbol-interleaved* beacon structure to overcome the drawback of the low transmission speed of acoustic signal and improve the *location update rate* [4].

Smartphone Processing: We perform preprocessing for the received acoustic beacon signal, e.g., adaptive filtering and wavelet decomposing, before signal detection. Transmit reference approach is utilized for the matched-filter estimation in the smartphone side [3]. The signal detection module is designed with better robustness by applying cluster detection and spectrum matching to identify signal-like interference. The demodulated information bit could be used to extract the pseudoID for each node. The synchronization is realized by tracking the demodulated signal in the time-domain, where the convergence of the tracking filter means the success of the synchronization.

We propose a dynamic TOA estimation scheme to obtain accurate ranging results by maximizing the TOA detection probability; along with multiple-threshold backward approach to ensure the detection of TOA path. To minimize the NLOS bias effects, we propose approaches for NLOS mitigation.

Server Processing: To minimize the computation cost in a smartphone, we offload localization and tracking process into the back-end server. To mitigate the outliers and missing data in the ranging measurement, we propose track-before-localization for the ranging results of each station. We further propose semidefinite programming (SDP) for global optimal location estimation by leaveraging the computational power of the server. To utilize the linear time varient feature of the unknown delay, we add delay-constraint into the location estimation for better robustness.

Achieved Performance: For the prototype of the Guoguo system, current experiment results demonstrated the promising features of our solution: low power and unnoticeable acoustic beacon, low-complexity anchor node (BOM price $<$ \$15 per node), high precision in anchor network synchronization ($< 10\mu s$), large coverage ($15 \sim 20$m), centimeter-level accuracy ($<$ 10cm), high refresh rate ($>$ 1Hz), robust under sound interference (up to 110dBA). When compared with commercial apps, Guoguo app show modest CPU utilization and network traffic (lower than Google Chrome) without interrupt the normal phone usage. This practical and robust ecosystem promises enormous new possibilities for novel indoor location-based services and applications.

Future Work: We plan to conduct more measurements to quantify the transmission power, maximum operation distance, human blockage, and potential health risk. The relationship among coverage, the minimum number of anchors, and real-world obstacles need to be exhaustively studied. To enable application in real scenario with strong background noise and realtime tracking requirement, more sophisticated interference-robust and time-efficient beacon transmission and coordination scheme should be developed. We have been approved to deploy our system in a campus museum, offer 3D positioning service and museum content guide and recommendation.

5. REFERENCES

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