Asynchronous Distance Measurement for Smartphone-Based Localization Exploiting Chirp Signals

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ABSTRACT

In this paper, we present an asynchronous, accurate, and real-time distance measurement method using chirp signals, which is capable of accurately locating and tracking, thus forming an ad-hoc network among smartphones in an indoor (e.g., smart meeting room) environment. We then implement our proposed method on top of commercial off-the-shelf smartphones without modifying their hardware or OS kernel. Our experimental results demonstrate that it takes <1 second to conduct network-wide distance measurements and the measurement error is $<10cm$ in at least 87% of the experiments.

Categories and Subject Descriptors

C.3 [**Computer Systems Organization**]: Special Purpose and Application-Based Systems – *Signal Processing Systems*

General Terms

Algorithms, Experimentation

Keywords

Distance measurement, Chirp Signal, Smartphone, SAN

1. INTRODUCTION

As smartphones become widely available in our daily lives, various research efforts were invested to effectively form an ad-hoc network of commercial off-the-shelf (COTS) smartphones. These smartphone-based ad-hoc networks (SAN) aims to provide context-driven services, e.g., smart meeting systems [1], in environments that are not equipped with pre-deployed infrastructures. Considering the fact that smartphones are standalone systems with high mobility, we need to satisfy a number of technical properties when forming a SAN, which include highly accurate yet cost-effective distance measurement between a pair of smartphones without having to modify their hardware or OS kernel, e.g., for intensive clock synchronizations.

The BeepBeep [2] is one of the well-known methods presented in recent years, which meets the requirements with negligible distance measurement errors ($<10cm$). However, there are two technical problems when we construct a SAN using BeepBeep. The first problem is derived from how the BeepBeep is designed to prevent overlapping chirp signals when measuring the distance. Assuming that a SAN consists of N smartphones, $N(N-1)$ 'beep' sounds must be made one-by-one to complete the network-wide distance measurements, consuming a significant amount of time. The second problem is related to the multipath effects caused by the speaker positions of smartphones, one at the rear and the other at the front, which negatively affect the accuracy of BeepBeep. Such erroneous effects increase the distance measurement errors, which in turn leads to imprecise context extraction due to incorrect localization of smartphones in a SAN.

In this work, we present a real-time method that can complete the network-wide distance measurements by simultaneously triggering multiple chirp sounds that are orthogonal to one another. The proposed method effectively suppresses distance measurement errors caused by the multipath effects by selecting either the front or rear speaker on-the-fly depending on device orientations. After implementing our proposed method on top of COTS smartphones as a software-only solution, i.e., not modifying their hardware or OS kernel, we demonstrate via real-world experiments that the distance errors are less than $10cm$ with an accuracy of over 87% while taking less than a second to measure the network-wide distances between two smartphones.

2. MEASUREMENT METHOD

To validate the feasibility of our proposed method we start off by measuring the distance between a pair of smartphones, denoted as devices A and B. The measurement is comprised of 2 steps. First, smartphones form a SAN to perform two-way sensing and self-recording. As illustrated in Figure 1, smartphones transmit their own designated chirp signals, each having different chirp frequency band. These signals are then captured by itself and the others. Unlike conventional BeepBeep where beep sounds are made one after another, we incorporate simultaneous beep

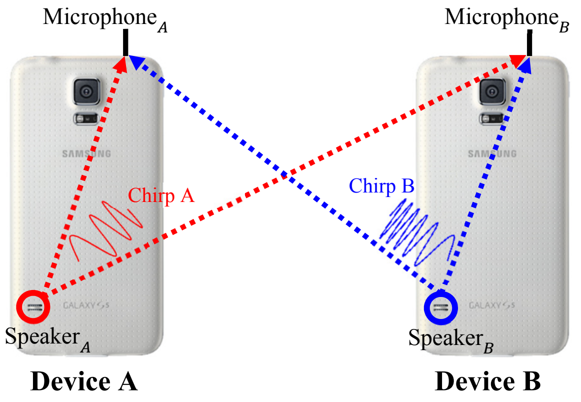

Figure 1. An example of two-way sensing and self-recording, in which devices A and B simultaneously emit different chirp signals in the recording state.

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transmission by exploiting the orthogonality of chirp signals. Consequently, we are able to accomplish network-wide distance measurements with a single round of overlapped 'beep' as opposed to the BeepBeep that sequentially makes $N(N-1)$ 'beep' sounds where N is the number of devices.

Second, the distances between a pair of smartphones are computed using the following equation:

$$\mathrm{D} = \frac{c}{2}\left((t_{A2} - t_{A1}) - (t_{B1} - t_{B2})\right) + K \qquad (1)$$

where c and K are constants representing the speed of sound and the sum of distances between the speaker and the microphone of each smartphone, respectively. As shown in Figure 2, t_{A1} and t_{B1} represent the time when the chirp signals emitted from device A and B are recorded by their own microphones (self-recording). Furthermore, the time of chirp B recorded by device A is denoted as t_{A2} and the time of chirp A received at device B as t_{B2}. Note that t_{A0} and t_{B0} represent the time when chirps A and B are physically emitted from their own speakers in Figure 2.

To determine the arrival time of signals, i.e., t_{A1}, t_{A2}, t_{B1} and t_{B2}, we employ a matched filter [3] that can infer the arrival time of chirp signals where chirps A and B are likely to be overlapped. After matched filtering, peaks of high magnitude, which denote a high cross correlation between a recorded signal and an original chirp signal, are located. Therefore, we can calculate the actual time of arrival by applying the matched filter.

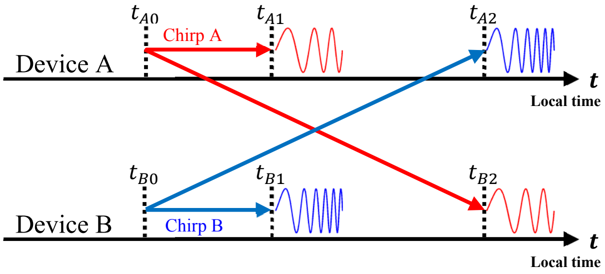

Figure 2. Illustration of two-way sensing and self-recording as local time line of device A and B.

3. EXPERIMENTAL EVALUATION

3.1 EXPERIMENTAL SETUP

To evaluate our propose distance measurement method, two Samsung Galaxy S5, one of the latest COTS smartphones, were used to build a SAN. These devices use Android 4.4.2 versions and are equipped with Bluetooth, Wi-Fi, 2GB RAM, and 2.5GHz quad-cores CPU.

We conducted experiments at a meeting room that has the length of 730cm and the width of 530cm. The temperature in the meeting room was maintained between 17 and 20°C, and two smartphones were placed on top of the U-shaped table that is of 406cm wide and of 240cm long. Furthermore, we suppressed all unwanted background noises to make it a quiet environment. We designed three test cases by varying smartphone orientations as follows:

- Case 1 (Back-Back): All smartphones are placed upside down making screens to face the table.
- Case 2 (Back-Front): One smartphone is placed on the table with front side facing upward while the other facing the table.
- Case 3 (Front-Front): All smartphones are placed on top of the table with front side facing up.

For each case, smartphones were separated 1m, 2m, 3m, and 4m apart from each other, and 30 distance measurements were accordingly made for each of the cases.

3.2 EXPERIMENTAL RESULTS

Figure 3 depicts the experimental results. Figure 3(a) plots the accuracy of distance measurement as we increase the inter-smartphone distance, where the accuracy is computed as the ratio of reliable distance measurement results ($<10cm$) to the total number of trials. The results indicate that the accuracy is mostly above 90% except for the Case 1 (having 87% accuracy) when inter-smartphone distance is 2m. Such phenomenon is derived from the fact that a single erroneous result is highly emphasized since we have a limited number of test trials for each scenario while there are only 4 error prone results out of 30 trials.

On the other hand, Figure 3(b) illustrates the average distance errors in Cases 1, 2, and 3. As we increase the inter-smartphone distance, we observed that the average distance errors also increased. This is because a small-sized room aggravates the multipath effects. In fact, devices are very close to a wall when the inter-smartphone distance is 4m.

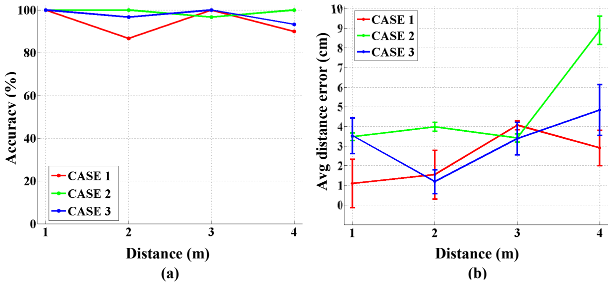

Figure 3. (a) Accuracy and (b) average distance error measurement for Cases 1, 2, and 3, in which y-axis indicates the real distance between devices A and B.

4. CONCLUSION

We proposed an accurate, asynchronous, and robust distance measurement method as a software-only solution. Our proposed method enables the development of highly-accurate infrastructure-less localization system for smartphones by overcoming the technical problems of BeepBeep when constructing a SAN. We conducted a variety of experiments in an indoor meeting room limiting all sources of noise, and demonstrated the accuracy is at least 87%. As a future work, we plan to evaluate our method in diverse environments including noisy places as well as to make it an adaptable system using multiple smartphones.

5. REFERENCES

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