Performance analysis of TDoA based Localization using SDRs*

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Abstract— **This paper presents the implementation of a low cost Time Difference of Arrival (TDoA) based localization system using Software Defined Radios (SDRs) and it shows reasonable accuracy. The sources of localization error are also discussed.**

I. INTRODUCTION

Localization is to use a set of transceivers at known locations to determine the position of a transceiver at an unknown location. Accurate localization is critical in many military and civilian applications, including surveillance, navigation, tracking, etc. Our concern is how to achieve accurate localization using inexpensive platforms. SDR [1] provides great flexibility and adaptability in system design, making low-cost localization solutions a reality. In this paper, the implementation of TDOA based localization system using SDRs is briefly presented. The main focus is to analyse the source of localization errors in real-world experiments.

II. THE SDR BASED LOCALIZATION SYSTEM

A. System implementation

As shown in Fig. 1, three TDoA measurements can be obtained from four SDR units, which are transmitted in a wireless way to implement localization of an (uncontrolled) emitter by a central processor.

Two key problems need to be tackled in TDoA based localization. One is to achieve accurate synchronization of multiple receivers, the other one is to obtain TDoA measurements. The first problem is solved by mounting a build-in GPS disciplined oscillator (GPSDO) module on each SDR unit, which can provide frequency reference to control the local oscillator of each SDR unit with accuracy of 0.01ppm. The claimed time accuracy of this module is +/-50ns. The second problem is studied using two co-located SDR units considering the baseline resolution constrained by the sampling rate and achievable synchronization accuracy of the system. The cross correlation is implemented on received signals to obtain sample delay, which corresponds to TDoA with knowing the sampling rate.

B. Field tests and results

In the practical implementation, the first step is to find a suitable emitter. We are interested in testing the platform in a relative long range (several kilometres), however the SDR unit do not have enough power. A self-made powerful emitter may violate the local RF signal rules (in Australia, it is governed by ACMA). Therefore, a local FM radio station (1CBR at 106.3MHz) at the Telstra Tower (-35.2755°,149.0978°) [2],located on the top of Black Mountain in Canberra, Australia, is chosen to verify the feasibility of the proposed solution. The drawback of FM signal is that the narrowband signal will give lower time accuracy comparing to wideband signal, but this will not influence the functionality of this localization system.

In the field test, four SDR receivers are deployed at different locations with GPS coordinates obtained from GPSDOs, SDR1(-35.2531°,149.1503°), SDR2(-35.2435°,149.0975°), SDR3(-35.2741°,149.1203°) and SDR4(-35.2408°,149.0463°), as shown in Fig. 2. The furthest SDR is 6.2 km from the emitter.

Three pairs of independent TDoA measurements will give an over-determined equations in 2D space, so [3] is used to estimate the emitter location. In Fig. 3, the blue stars are the four SDRs, the red point denotes the true emitter position, the green points denote the localization results, which obeys Gaussian distribution, using 20 groups of TDoA measurements from 4 SDR receivers and the blue point is the Gaussian mean of the location estimation. The mean localization error is 44.5065m.

III. LOCALIZATION ERROR ANALYSIS

To enhance the localization accuracy, analyzing the error sources will help. Some errors, such as Non-Line of Sight(NLoS) and the uncertainty of sensor location, are generic errors to all (time based) localization systems, while the sampling error and synchronization error are specific errors to this SDR platform.

A. NLoS error

The availability of power supply and wireless communication will facilitate the operation and data collation of SDRs greatly, so the tests were implemented in urban areas. However, there are buildings around that can block the direct signal propagation path and the signal travels longer distance before being received, so the accuracy of localization suffers from NLoS error. Unfortunately, with limited number of SDR receivers and especially in this passive source localization scenario, existing methods that remove the measurements influenced by NLoS or mitigate NLoS error according to NLoS distribution cannot be used.

B. Uncertainty of sensor (SDR receiver) location

In localization systems, accurate sensor locations serve as ground truth in determining a target at an unknown location.

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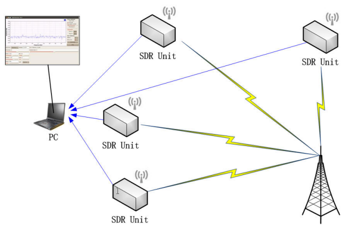

Fig. 1. The framework of the system

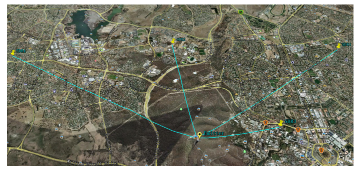

Fig. 2. Deployment of 4 SDR receivers

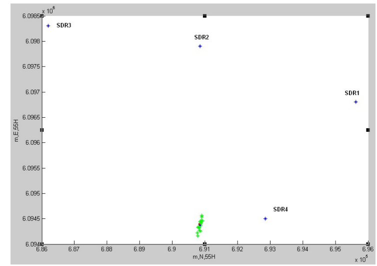

Fig. 3. Localization result (4 SDRs) in 2D

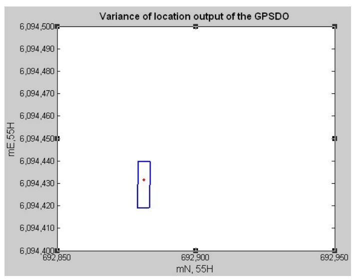

Fig. 4. Sensor location range obtained from GPS sensor

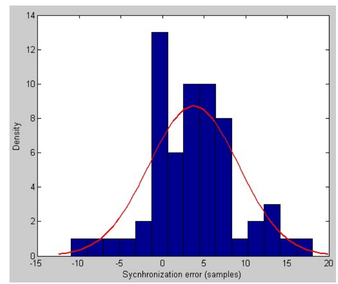

Fig. 5. The statistic of synchronization error

In this implementation, sensor location can be obtained using build-in GPS Disciplined Oscillator (GPSDO) of each SDR unit. The location output accuracy of the GPSDO for one SDR is investigated. As shown in Fig. 4, all outputs of GPS sensor lies in the blue rectangle, with the size of 4.3977m * 20.7111m and the red point is the mean value. The variance of GPS outputs is 1.03249e-7° and 5.45976e-9° for x-axis and y-axis respectively, which are very small, so it only contributes to minor influence on the result. Moreover, in real-world experiments, this error can be further reduced by calculating the mean value of a large amount of measurements.

C. Sampling error

Sampling error influences the accuracy of TDoA measurements obtained from cross correlation of signals received by two SDRs and the quantity is determined by sampling rate. The highest sampling rate of this SDR unit is 25M Sps, which constraints the time resolution to 40ns and baseline resolution to 12m. During the experiments, some TDoA measurements were found to be extremely noisy, which is caused by temporary malfunction of the hardware or big noise source in the environment. To identify these measurements, a threshold is set to 0.91, only TDoA measurements with cross correlation coefficient higher than this threshold will be used in location estimation. The threshold is calculated according to the fact that the difference of 8500 continuous samples between two sequences out of a total length of 1M samples, which corresponds to 100km range difference, will still give the coefficient of 0.917. In addition, the empirical value of SDR gain that gives optimized signal-to-noise ratio (SNR) is 40dB. Actually, by selecting TDoA measurements properly, the influence of sampling error is small.

D. Synchronization error

Synchronization of SDRs is achieved through GPSDO which provides frequency and time reference to each SDR. To investigate the synchronization accuracy, two co-located SDR nodes were used with attempt to minimize the influence of other errors, such as the influence of signal attenuation through different paths, thus focuses on synchronization error only. The influence of NLoS error is also reduced by putting two SDR units in the sight of the emitter. 60 TDoA measurements were implemented and the result shows that the synchronization error, measured in samples, obeys Gaussian distribution approximately, as shown in Fig. 5. The mean error is 3.5 samples, corresponding to 42m, and the variance is 29.2 samples. Therefore, synchronization is the largest error and it is the combined influence of frequency and time error of the GPSDO. Currently, we are looking at different synchronization methods with higher accuracy.

IV. CONCLUSIONS

In this paper, the implementation and the error source of a low-cost TDoA based localization system using SDRs are discussed. Localization accuracy can be further enhanced by increasing the sampling rate of SDR and reducing the synchronization error.

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