Signal of Opportunity Based TDOA Positioning Using Analog TV Signals

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***Abstract*—The ability to self-localize is an essential requirement for many systems. Mostly, this is accomplished by using a Global Positioning System (GPS) receiver. However, in some situations, the GPS receiver is disabled by external factors. Signal-Of-Opportunity (SoOP)-based localization is a popular substitute solution. TV broadcasting can be utilized for SoOP-based self-localization. In this paper, we collect measurements of Phase Alternating Modulation (PAL) analog TV broadcasting to aid the localization model. Specifically, we use these measurements to achieve a Time-Difference Of Arrival (TDOA) localization of one receiver with the knowledge of the coordinates of four transmitters and a reference receiver. The histogram of the localization error shows that the average error hits the theoretical limit of the employed bandwidth or the limit set by the time resolution of the samples.**

***Index Terms*—Signal-Of-Opportunity, TDOA, PAL, analog TV, localization, GPS.**

I. Introduction

Localization systems such as the GPS and Global Navigation Satellite System (GNSS) are widely used in different applications. These systems are susceptible to jamming [1] and spoofing [2]. As an alternative, SoOP-based localization systems, which rely on the available signals in the surrounding, are nowadays gaining growing interest [3]–[5]. While SoOP signals do not have the aforementioned limitations, their main problem is estimating the clock of their transmitters [3].

Different localization methods using TV signals as an SoOP have been proposed in the literature [6]–[8]. TDOA localization technique is often used with TV signals. A typical setup to self-localize a moving receiver using the TDOA technique consists of several transmitters, a reference receiver, and the moving node to be localized [9]. TV transmission has the advantage of a wide coverage area, low-frequency carriers, and large bandwidth [10]. However, the large bandwidth itself is a drawback if the reference receiver has to share its signal with the moving receiver [11]. Distributed TDOA, where the features of the received signals are extracted locally and shared with the other node, can decrease the required communication bandwidth between the receiving nodes [12].

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Additionally, TDOA localization technique requires accurate time synchronization between either the transmitters [13] or the receiving nodes. This requirement increases the computational cost and lowers the localization accuracy [14]. Thus, it is an advantage to use an alleviated time synchronization scheme such as in [15], [16], or to remove the need for it such as in [17].

Many practical studies exploited different signals to achieve localization such as digital TV [8], NTSC analog TV [18], LTE [4], WLAN [16], or a mix of SoOPs [5], [7]. However, no practical study employed PAL analog TV signals. PAL analog TV broadcasting system is still widely used in many countries around the globe [19], [20]. PAL differs from its rivals in parameters such as the number of lines per frame, field frequency, and bandwidth [21]. A detailed description of the standard can be found in [22].

In this work, we present the measurement results of an outdoor TDOA SoOP-based receiver-localization campaign. We employ a reference receiver to collect signals required for the TDOA algorithm. In the applied algorithm, no time synchronization scheme is employed or assumed between different nodes. The SoOPs are assumed to be 4 spatially different analog PAL TV broadcasting sources. The positions of the reference receiver and the SoOP sources are predefined. Only the position of the target receiver is to be determined.

The rest of the paper is organized as follows. In section II we introduce the signal model and the measurement setup. Section III covers the process of collecting the measurements. In section IV, we discuss the employed algorithm. Section V presents the localization results of applying the algorithm to the collected data. Finally, we summarize our work and conclude the paper in section VI.

II. Measurement Setup

A. Signal Model

We adopt the signal model of PAL systems B and G. These systems are characterized by a channel bandwidth of 7MHz and 8MHz, respectively. The video bandwidth is 5MHz. The sound is Frequency Modulated (FM) and separated by $+5.5$MHz from the luminance carrier [23]. In PAL systems B and G, the TV broadcasting signal consists of frames. A frame sweeps the whole screen display in 40ms. A frame consists of 2 fields, of 20ms each. PAL transmission has 625 lines/frame. Each field starts with a Vertical Synchronization (VSYNC) signal as shown in Fig. 1 and each line starts with a Horizontal Synchronization (HSYNC) signal [22].

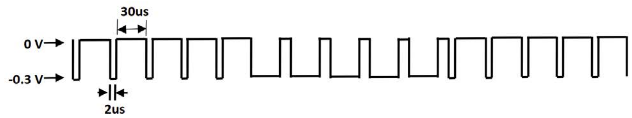

Fig. 1. Vertical synchronization signal VSYNC preceding every field.

B. Setup

In our system, we have 2 receiving nodes: the target receiver that we localize and the reference receiver. Each receiving node consists of 4 National Instruments (NI) 2930 Universal Serial Radio Peripheral (USRP)s connected to a common Octoclock as shown in Fig. 2. The Octoclock allows multiple USRPs to use the same physical clock, thus, unifying their timing. The USRPs interface with a host computer through a switch. Unlike GPS-based localization where the transmitters are synchronized, in our scenario, every transmitter has its independent clock. Instead, we aim to synchronize the 2 receivers without using a time synchronization scheme. This requires unifying the sampling time of different received stations through the Octoclock so that the relative time offset between both receiving nodes is common for all channels. Additionally, employing the reference receiver allows applying TDOA as the PAL signal does not have any information about the transmitter's time or location.

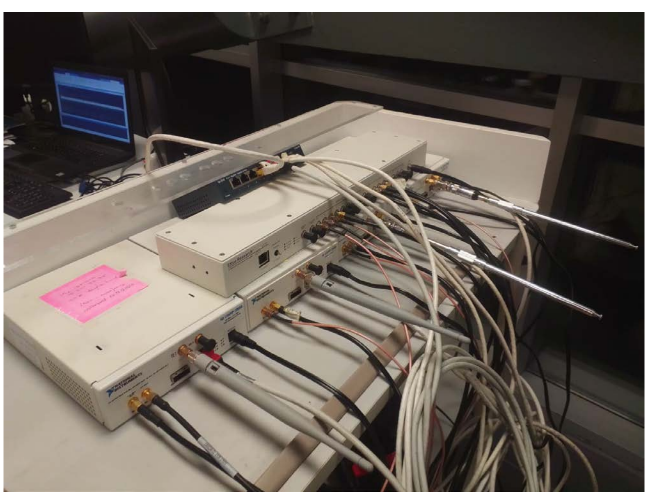

Fig. 2. The setup of a receiving node

To configure the USRPs, we use GNU Radio framework with its graphical interface known as GNU Radio Companion. The flow graph for a receiving node is as shown in Fig. 3. The flow graph consists of 2 types of blocks: USRP source and file meta sink. USRP source block interfaces with the USRP hardware and allows to change its configuration. File meta sink blocks save the received signal samples, in addition to some extra information such as the received signal bandwidth and timestamp of the first received sample.

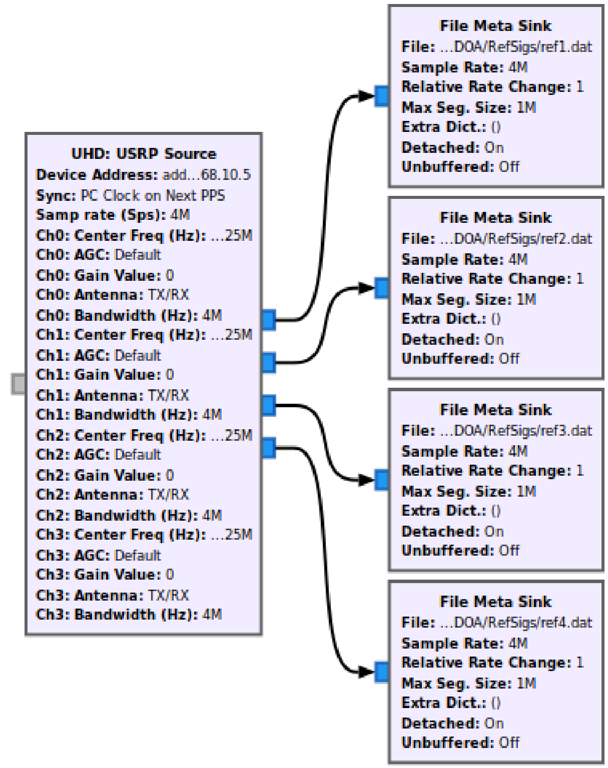

Fig. 3. The GNU Radio flowgraph of a receiving node.

TABLE I
RECEIVER PARAMETERS

Parameter	Value
f_{c_1}	479.25MHz
f_{c_2}	551.25MHz
f_{c_3}	679.25MHz
f_{c_4}	687.25MHz
3-dB BW	4MHz

III. MEASUREMENT CAMPAIGN

The measurement campaign took place in Istanbul, Turkey. The scenario consists of 4 analog TV broadcasters and 2 receiving nodes distributed as shown in Fig. 4. The exact geographical coordinates of the SoOP transmitters and receivers are given in Table II. Due to the relatively low height of the transmitters and the territory shape between the transmitters and receivers, a Line-Of-Sight (LOS) could be achieved between the receivers and Tx1 only. Thus, we receive the 4 channels from Tx1, then, we apply signal processing on received signals of channels 2 to 4 to have the same effect as if they are transmitted from Tx2, Tx3, and Tx4, respectively.

TABLE II
GEOGRAPHIC COORDINATES OF NODES.

Node	Coordinates	
Tx1	$41°00'59''N$	$29°03'57''E$
Tx2	$41°04'06''N$	$28°59'31''E$
Tx3	$41°08'39''N$	$29°06'03''E$
Tx4	$40°50'20''N$	$29°07'25''E$
rov	$41°05'27''N$	$29°05'30''E$
ref	$41°00'56''N$	$29°05'55''E$

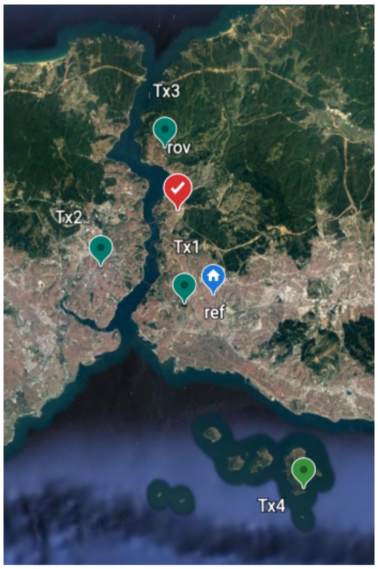

Fig. 4. Map of the testing scenario.

IV. The Algorithm

The applied algorithm is similar to that in [6]. First, we detect the fields of received TV channels at each receiving node. Within a window of 1 field duration, we detect 1 field from each channel. The time of fields is considered as Time Of Arrival (TOA). The TOA is relative to the receiver's local time, and not to the absolute time. The differential TDOA at the receiving node is then formulated as:

$$T_{ij}^{mn} = T_{ij}^{m}(\tau(m)) - T_{ij}^{n}(\tau(n)) = d_{ij}^{mn}/c, \qquad (1)$$

where $T_{ij}^{m}(\tau(m)) = T_i^m - T_j^m$ is the TDOA obtained by differentiating two TOAs (T_i^m and T_j^m) of the signal from the mth transmitter measured at 2 separate receivers, and d_{ij}^{mn} is the difference between TDOA-equivalent distances. The differential TDOAs remove the transmitter's nuisance parameters such as the transmission time. We apply the localization algorithm to the recorded signals using MATLAB.

V. Measurement Results

For the aforementioned setup, the achieved localization error through detected fields and its histogram are as shown in Fig. 5 and Fig. 6, respectively. It can be seen that the localization error in the X and Y directions is on average below 500m. However, a spike in the localization error happens from time to time as the receiving hardware drops samples. This is mainly due to hitting the Ethernet maximum capacity in the connection between the USRPs and the host computer in one or both receiving nodes.

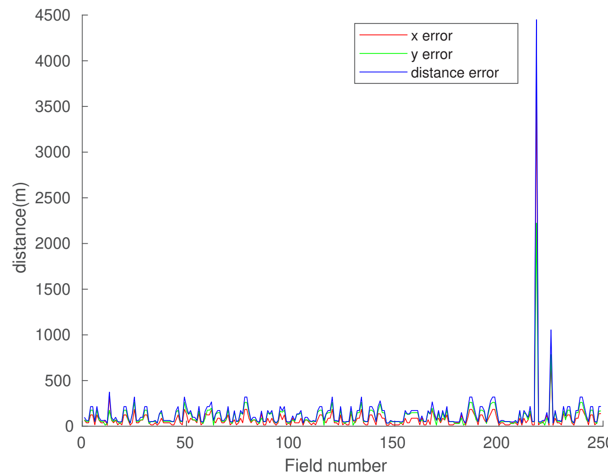

Fig. 5. Localization error through fields.

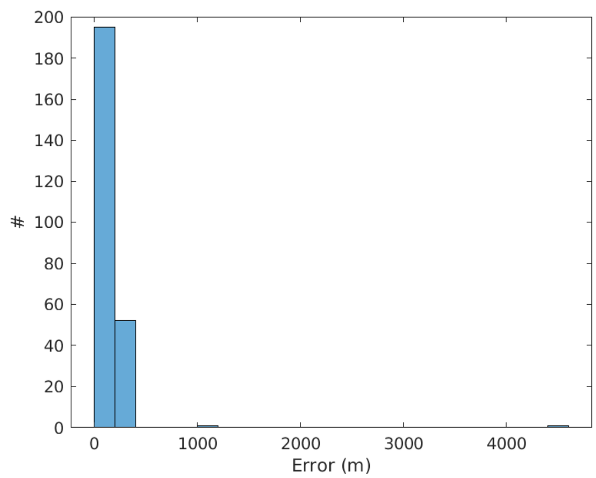

Fig. 6. Localization error histogram

To improve the localization results, the detected X and Y coordinates can be smoothed using a moving average filter. The smoothing operation decreases the average error, so that the overall localization error can go below a 100m, as shown in the localization error through fields and its histogram after smoothing the detected coordinates in Fig. 7 and Fig. 8, respectively.

The minimum achievable error E in detected TDOA depends on the bandwidth BW as shown in equation (2).

$$E \geq \frac{C}{BW}, \qquad (2)$$

where C is the speed of light [24]. Considering the 2 dimensions of X and Y, and the bandwidth, the minimum error is

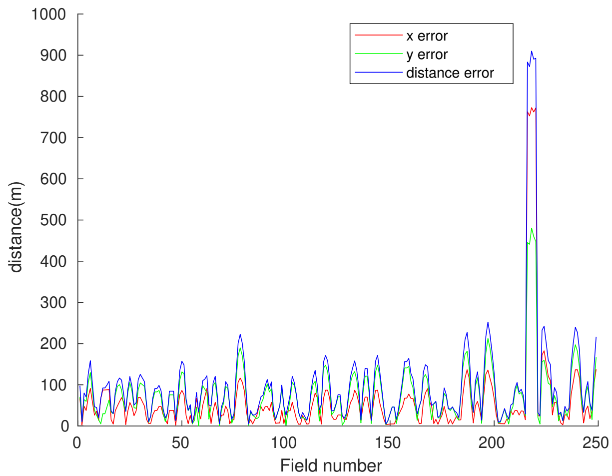

Fig. 7. Localization error though fields for after smoothing the detected coordinates.

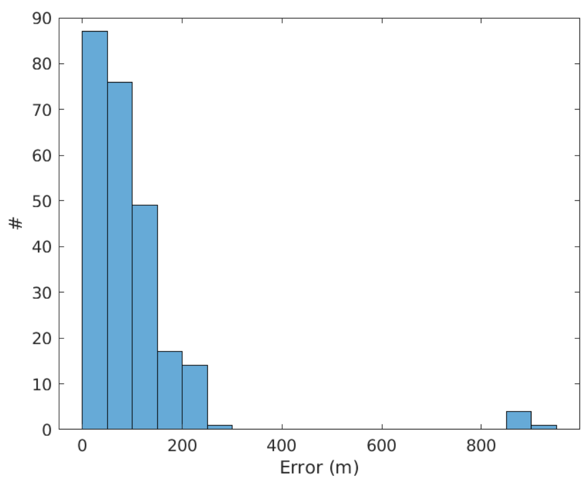

Fig. 8. Histogram of localization error after smoothing the detected coordinates.

around 105m. The error histogram show that the majority of the localization error falls within the same tab below 200m. The error histogram for the smoothed coordinates shows a performance better than the theoretical minimum achievable error.

VI. Conclusion

In this work, we presented the measurement results of TDOA-based localization using the collected PAL analog TV broadcasting signals as an SoOP. We discussed the details of the signal structure and the used setup. We presented the hardware and software used in performing the measurements. Collecting the measurements using a drone can further provide a solution for the drone localization problem in GPS-denied environments. Introducing a tracking algorithm such as Kalman filter shall enhance the achieved accuracy.

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