ALPS: The Acoustic Location Processing System

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ABSTRACT

We demonstrate the Acoustic Location Processing System (ALPS), an ultrasonic Time-Of-Flight (TOF) and Time-Difference-Of-Arrival (TDOA) localization system for mobile devices. ALPS capitalizes on the ability of smartphones to detect audio above the human hearing range and does not require any additional hardware on the receiving side. Synchronized, multi-channel beacons deployed in the environment periodically send time-multiplexed ranging signals consisting of ultrasonic chirps. Each mobile device runs an application that records a snapshot of audio, determines the Time Of Arrival (TOA) or TOF of the captured ultrasonic signals and then uses a cloud-based solver to compute its location. Bluetooth Low Energy (BLE) hardware integrated into the beacons allows for the identification of the captured ultrasonic signals in order to map them to individual transmitters and provides additional RSSI based location information. The relatively slow propagation of sound allows for accurate ranging in larger open spaces. A cloud-based floor-plan geometry aware location solver and an advanced beacon-placement algorithm aid in the elimination of localization errors and reduce the number of beacons required to cover a given space.

1. SYSTEM DESCRIPTION

ALPS is an indoor ultrasonic ranging system that can be used to localize modern mobile devices like smartphones and tablets in 2D space without requiring any additional hardware on the receiver side. The method uses a communication scheme in the audio bandwidth, just above the human hearing frequency range where mobile devices are still sensitive. ALPS uses a variant of the ultrasonic modulation technique described in [3], where multiple beacons send time multiplexed ranging signals to any number of mobile receivers. The overall architecture in Figure 1 shows the main components which include the beacons, the mobile device that is being localized. The beacons are time synchronized using an 802.15.4 radio to enable high resolution TDOA ranging given the geographical origins of the signals. The beacons continuously broadcast their transmission schedule via BLE to allow every receiver to map its captured ultrasound signals to the beacon that sent them. Once a receiver has successfully computed its location using TDOA ranging, it may synchronize itself to the transmitting infrastructure as described in [2]. This allows TOF ranging to be performed, reducing the amount of ultrasound signals that need to be captured successfully. Additional information from Inertial Measurement Unit (IMU) sensors on the phone and BLE RSSI data from the beacons is used to filter location estimates.

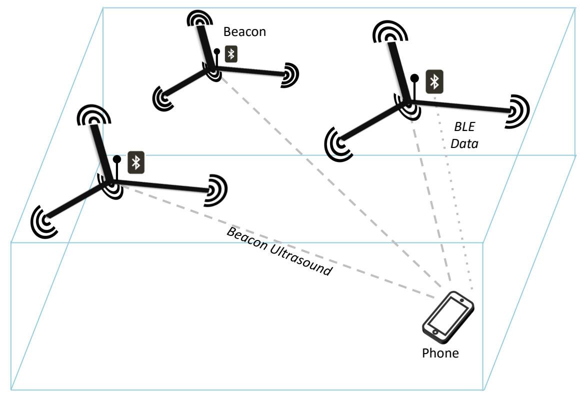

Figure 1: System Architecture

2. BEACON HARDWARE

Figure 2 shows a diagram of an ALPS beacon. In our deployment, the beacons are mounted on tripod stands

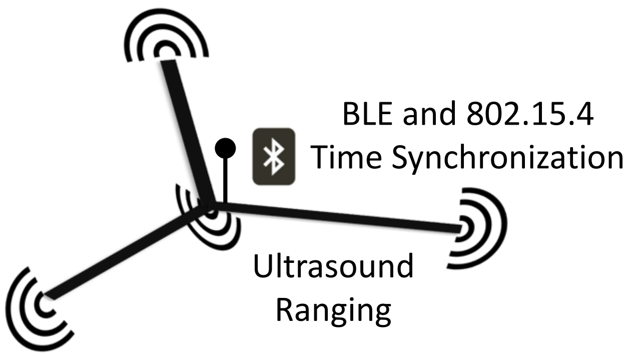

Figure 2: ALPS Beacon

that will be placed throughout the target rooms. Each beacon consists of a multi-channel speaker array, which can broadcast ultrasonic ranging signals from different sides of its casing which has a radius of $1m$. The signals are transmitted through omnidirectional horns, which disperse the ultrasound in a spherical pattern to obtain optimal signal coverage. Figure 3 and Figure 4 show the primary and secondary PCBs of an ALPS beacon respectively. The primary PCB is responsible for time synchronizing to other beacons via 802.15.4 and playing back the ranging signals. The secondary BLE PCB allows for coarse time synchronization to the receivers using the method detailed in [1].

3. RECEIVER AND SOLVER DESCRIPTION

The receivers can be any mobile device sensitive to up to $24kHz$ of audio bandwidth that runs our localization software. The user downloads an application which includes a map constructed during installation. As the user walks around the room, the application tracks the user and provides the current location. The application will be demonstrated on an iOS device.

Each receiver is responsible for demodulating incoming ultrasound ranging signals and determining the TOA or TOF of each signal. These values are then transmitted to a cloud-based solver, which solves for the location of the receiver based on the received TOA/TOF values, the location of the beacons, the receiver's IMU data, the BLE RSSI data from the beacons collected at the receiver and the floor-plan geometry of the target area. By combining information from all of these inputs, the solver is able to eliminate false solutions and reduce multi-path error and hence reduce the number of beacons required for localization. An advanced beacon placement algorithm which calculates the Geometric-Dilution-Of-Precision (GDOP) over the entire target area determines the optimal placement for beacons in order to exploit the floor-plan geometry to further minimize the amount of beacons that are required.

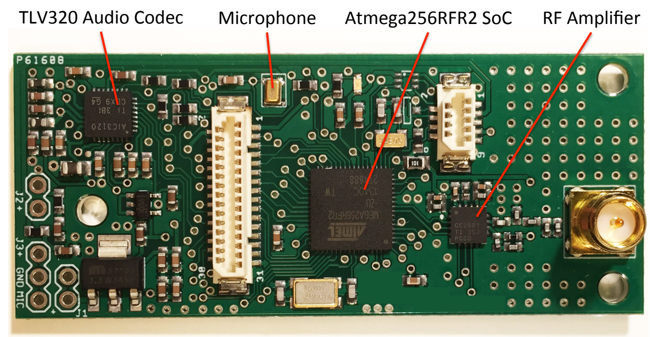

Figure 3: ALPS Beacon Primary PCB

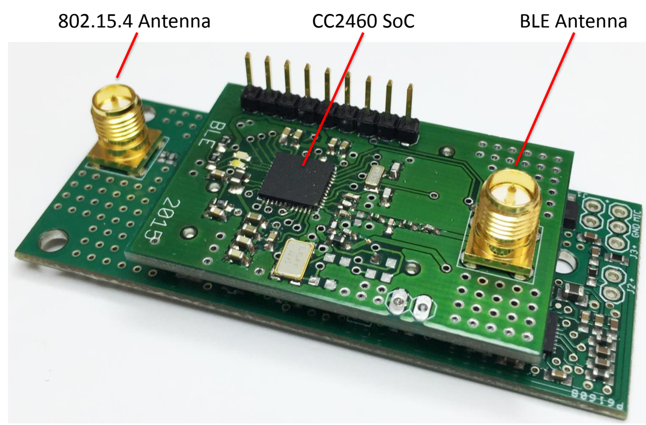

Figure 4: ALPS Beacon Secondary BLE PCB

4. REFERENCES

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[2] P. Lazik, N. Rajagopal, B. Sinopoli, and A. Rowe. Ultrasonic time synchronization and ranging on smartphones. In *IEEE Real-Time Applications Symposium (RTAS 2015)*. IEEE, 2015.

[3] P. Lazik and A. Rowe. Indoor pseudo-ranging of mobile devices using ultrasonic chirps. In *Proceedings of the 10th ACM Conference on Embedded Network Sensor Systems*, pages 99–112. ACM, 2012.