Acoustic-Based 3D Positioning System

Advancements in Spatial Awareness through Acoustic-Based 3D Positioning Technology

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Subject Area

Wireless Communications

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Introduction: A feasibility study was conducted for an acoustic localization solution involving caps with integrated LED screens developed by Dynavisual, as illustrated in Fig. 1. At large events such as concerts or sports gatherings, where numerous caps are worn simultaneously, they collectively form an expansive display. Accurate cap localization is paramount for achieving a clear image on the LED screen. The primary objective of this study was to investigate the viability of employing sound to determine the position of each cap.

Approach / Technology: The proposed solution entails fixed installed speakers emitting unique signals for each speaker. A microphone records these signals, and the time difference between their arrivals is calculated. Considering the speed of sound, the Time Difference of Arrival (TDoA) algorithm is used to calculate the position of the microphone. To ensure signal distinctiveness, signals with good auto- and cross-correlation properties were sought. Two signal types, chirps and Gold codes, emerged as effective solutions. A chirp is a sine function that continuously changes its frequency over time. Chirps exhibit excellent autocorrelation properties, peaking precisely when the signal aligns with itself. However, distinguishing non-correlating chirps poses challenges, making them suitable only for Time Domain Multiplexing (TDM). Gold codes offer an optimal solution with strong auto- and cross-correlation properties, enabling identification for each speaker. The modulation with a cosine carrier facilitates Frequency Domain Multiplexing (FDM), making the system faster for precise detection of moving objects. To address the non-idealities of the hardware and the channel, the signal is demodulated, filtered, and correlated. An algorithm was designed to handle reflections, comparing auto-correlation peaks to side peaks within a specified range. The dynamic range, representing the ratio between the peak and the highest peak nearby, is utilized to identify outstanding peaks as the line-of-sight signal. To mitigate signal interference, various multiplexing techniques, particularly TDM and FDM, were employed. TDM proves reliable for static positions, while FDM offers stability for moving positions but faces bandwidth constraints. To achieve precise synchronization necessary for TDoA, extensive monitoring of interfaces was undertaken to reduce delays. The goal was to reduce delays to less than 0.02 ms. For position calculation, a Least Squares method was employed, providing flexibility for varying speaker numbers, with a minimum of five essential for 3D localization. Simulations indicated increased accuracy with more speakers. In instances where varying speaker positions along a certain dimension are not feasible, strategic error simulation and mitigation become crucial, especially in venues with spatial constraints. Efforts focus on minimizing errors within the plane, where spectators are situated, ensuring a clear and undistorted overall picture. An experiment was conducted, as shown in Fig. 2. Six speakers were placed on two floors. The position of the microphone on the stairs was changed (Fig. 3) and computed.

Conclusion: Simulations highlighted the pivotal role of speaker placement. In a simulated setup and subsequent experimentation, the system proved highly reliable, as shown in Fig. 3. The measurement closely aligned with simulation predictions. In the corners of Fig. 3, it can be observed, that reflections indeed caused issues in the position calculation.

Fig. 1: System overview showing the speakers and the cap that should be located.
Own presentment

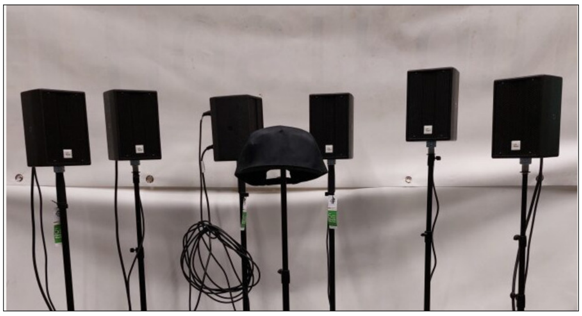

Fig. 2: Speakers and microphones are placed in the Building 8 at OST Campus - Rapperswil.
Own presentment

Fig. 3: Measurement results with the setup shown in Fig. 2.
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