Sound Based Localization System for Safety Applications in Underground Mining

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***Abstract* — We present a *sound based localization system (SBLS)* which was developed within the RFCS-project *FEATureFACE*. It is capable of 1D-, 2D- and 3D-positioning around a central "machine". The primary design goal was the reliable localization of miners around dangerous machinery in the tough environment of a coal mine. – The system utilizes time-of-flight (TOF) measurement of coded audible signals within the audio band, which are highly immune to ambient noise. In the default configuration positioning information is only calculated and evaluated on the central base station. For demonstration purposes at the *Indoor Localization Competition 2016* the system was equipped with a back channel, which displays the coordinates at the mobile station.**

Keywords — sound based localization system, safety, mining

I. APPROACH

The description in this chapter is partially taken from [1].

Collision Avoidance Systems (CSA) are based on a number of different physical principles. In the harsh environment of underground mines robust technique is required. Because of the large number of metallic structures found in this area, electro-magnetic based systems are prone to multi-path errors. As an alternative approach a sound-based localization system was developed.

A. *Measurement Signals*

The system is based on TOF measurements that are performed by emitting a particular measurement signal from a number of loudspeaker, and by simultaneously recording the signal at the location of interest employing an omnidirectional microphone.

The first obvious choice of a frequency range would have been ultrasound (~40 kHz) which would have had the advantage of being inaudible. However, as the atmospheric attenuation increases with f^2 which precludes distance measurements within the desired range, we have chosen to use audible signals.

As our position estimation system needs to deal with a noisy acoustic environment, we chose frequency-modulated (FM) measurement signals which exhibit beneficial time-bandwidth characteristics. In addition, our system was designed as to be able to consider the Doppler-shift of the measurement signals that occurs as soon as the miners are moving.

Hence, we have applied pairs of hyperbolic frequency-modulated signals between two frequencies f_1 and f_2. Choosing $f_1 < f_2$ results in an up-chirp signal, while $f_1 > f_2$ gives a down-chirp signal. Combining an up-chirp and a down-chirp signal allows for a compensation of the Doppler-shift as the correlation peaks of these signals are always shifted in opposite directions regardless of the direction of the movement.

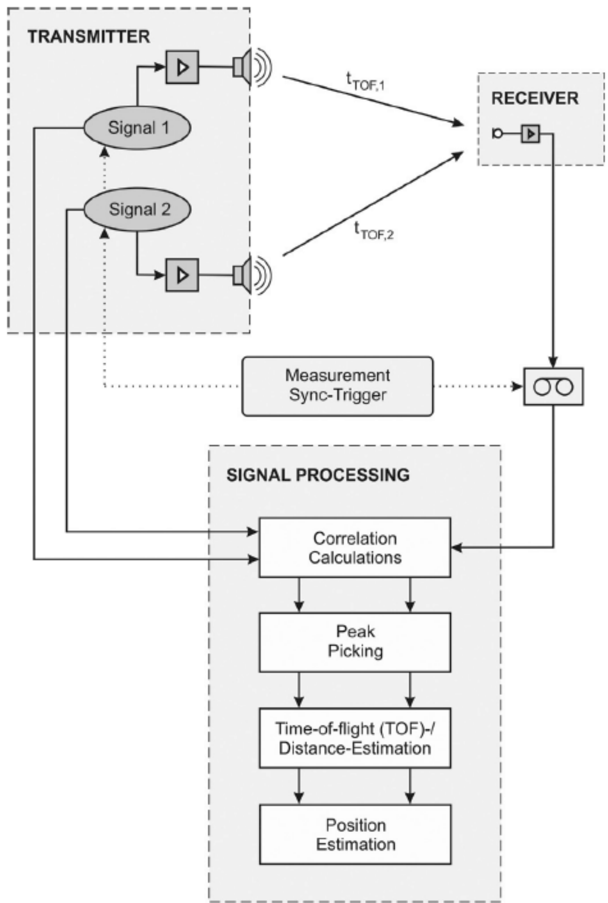

Fig. 1. Acoustic positioning principle (from [1])

B. *Correlation processing and peak-picking*

As soon as the received signal s_r is available, an estimate of the cross-correlation between s_r and the measurement signals $s_{m;p;q}$ can be computed. For efficiency reasons, we facilitate the Fast Fourier Transform (FFT) function available on our DSP board, in order to calculate the correlation signal in the frequency domain.

Potential reflections of the measurement signals in the mine environment may result in higher correlation peaks than the peak of the line-of-sight signal. Thus, we have applied a peak-picking algorithm that determines the most prominent peaks from which the multipath components may be disregarded. As an input, the maximum number of peaks to be picked N_{pk}, and a threshold level s_{th} above which maxima are searched for, are given.

C. *Distance, position and velocity estimation*

Based on the correlation peak information returned from the individual mobile tags, and on information on the loudspeaker positions and directions of emission, the position estimation algorithm calculates estimates of the tags' respective positions and velocity vectors (details to be found in [1]).

II. DEPLOYMENT REQUIREMENTS

The prototype system consists of up to six loudspeakers which are mounted on one side or in the center of the observation area. Fig. 2 depicts the measurement on a mining machine within a trainings mine in Germany. As these tests were performed in 2D, all loudspeakers where installed on a single plane (wooden framework attached to the machine). For 3D a different rack will be designed, which's approximately dimension might be 3m x 3m x 0.5m.

A base station (appr. 1m x 1m x 1m; 40 kg; power requirement 230 V~, 150 W) is placed near the area of loudspeakers. The mobile tag consists of a hard hat equipped with a microphone, a belt unit (data processing, radio link, battery) and a device for displaying the current location.

A single radio frequency channel (433.92 MHz) is utilized for synchronization purpose between the mobile tags and the base station.

Fig. 2. Stationary measurement setup. The loudspeakers were mounted on a construction of wooden rails. The hard hats (circle marks), and mobile tags were mounted on supporting stands. (from [1])

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