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GUIMUS: a smartguide based on an Acoustic FSK protocol

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Abstract—**This paper presents a smartguide prototype based on the detection of high frequency acoustic signals by means of the user's portable device. An FSK communication protocol is used to tag the different exhibitions ensuring at the same time a high tolerant to the Doppler shift caused by the user's movement. This system has been implemented on an Android-based platform to obtain a set of preliminary results that corroborate the feasibility of the proposal.**

Keywords— Acoustic identification, FSK communication, Android-based platform

I. INTRODUCTION

Acoustic technology has been profusely used in the design of indoor positioning systems, and today it is considered a classical solution to this technological challenge [1]. Since the appearance of the first proposals at the beginning of this century [2-4], many general-purpose Acoustic Local positioning Systems (ALPS) have been developed that included more and more advanced signal processing techniques, such as Code Division Multiple Access [5-7], Doppler shift compensation [8-9], Multiple Access Interference cancellation [10] and multipath compensation [11].

In the recent years we have witnessed a renewed interest in the design of ALPS that incorporate a portable device as the mobile node. Within this category we can find systems like *Beep* [12], and a later evolution of this work [13], that use a Personal Digital Assistant (PDA) to emit short ultrasonic pulses that are detected by an array of six microphones, connected through a WLAN with a central process unit. These systems achieved positioning accuracies below 70 cm in 90% of cases, improving to 40 cm in positions away from walls and corners. A similar system is proposed in [14, 15] where a smartphone is used to emit short 21.5 kHz ultrasonic pulses detected by an array of four microphones. This system achieved errors below 10 cm by minimizing a positioning cost function. A different approach is proposed in the *BeepBeep* ranging system [16], where the authors present a two-way sensing technique to estimate the relative distance between a PDA and a smartphone. By measuring the TOF of chirp signals with frequencies between 2 and 6 kHz, this system achieved positioning errors of 5 cm for distances below 4 m. Later, several works benefited from the *BeepBeep* ranging technique to develop different relative indoor positioning systems among smartphones and tablets [17, 18, 19], reporting average positioning errors between 10 and 30 cm.

One of the main disadvantages that have been traditionally attributed to ALPS systems is their limited coverage, due to both the narrow beamwidth and short propagation range of high frequency acoustic signals. Nevertheless, this in principle unfavorable feature could be exploited to conduct a precise short-range cell identification. In this work we propose the design of a smartguide based on the detection of high frequency acoustic signals with the user's mobile device. These signals consist in binary codes FSK modulated that are incoherently demodulated by the user to uniquely identify the corresponding emitter, which is in turn tagging a particular exhibition. On the main advantages of using the FSK protocol instead of more evolved communication schemes is the high resilience to Doppler shift of frequency modulated signals which has been already proven by the authors in the past in the context of a general-purpose ALPS [20]

The rest of the work is organized as follows. Section 2 describes the main features of the GUIMUS system. Section 3 includes the system implementation and some preliminary results. Finally, Section 4 presents the main conclusions and future work.

II. SYSTEM DESCRIPTION

A. Emitter and signals

To tag the different exhibitions we have used a Kingstate KSSG1708 high frequency transducer [21] that presents a maximum frequency response at 20 kHz, with a Sound Pressure Level of 87 dB @ 10 cm (see Figure 1).

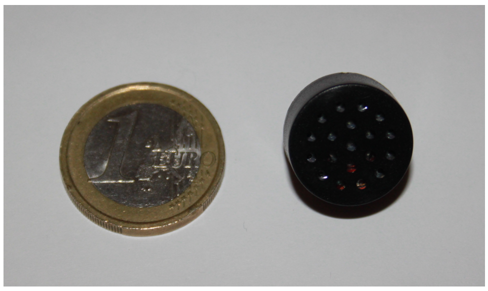

Fig. 1. Picture of the Kingstate KSSG1708 transducer.

This transducer is driven by a low-cost microcontroller that stores a BFSK modulated binary code that uniquely identifies it. The length of this code is *N* bits, where *N* is the first integer above $log_2 M$, and M is the number of exhibitions to be tagged. These bits are BFSK modulated using the frequencies of f_0 = 18 kHz and f_1 = 20 kHz for bits 0 and 1 respectively, with one carrier cycle per modulation symbol, thus giving an estimated message duration T_m:

$$T_m \approx \frac{N}{2}\left(\frac{1}{f_0}+\frac{1}{f_1}\right) \approx N \times 52.8\,\mu s \qquad (1)$$

This message is preceded by a chirp header used to signal the beginning of the message when performing the incoherent demodulation. The chirp waveform sweeps over the frequency range 16 kHz to 22 kHz in a period of 2 ms, thus featuring a time-bandwidth product of 12 that ensures good auto-correlation properties. These signals are transmitted with a repetition period of 80 ms to avoid the interference of the current emission with the echoes of previous ones.

B. Receiver

As stated in the introduction, GUIMUS is a smartguide based on the user's portable device. This device demodulates the signal described above by following the non-coherent FSK scheme shown in Fig. 2. As shown in this figure, the received signal is first digitized at a sampling rate fs = 96 kHz and then matched filtered to signal the beginning of the binary message through a correlation peak. This message is then band-pass filtered at the FSK carrier frequencies to carry out an envelope detection that feeds the decision stage.

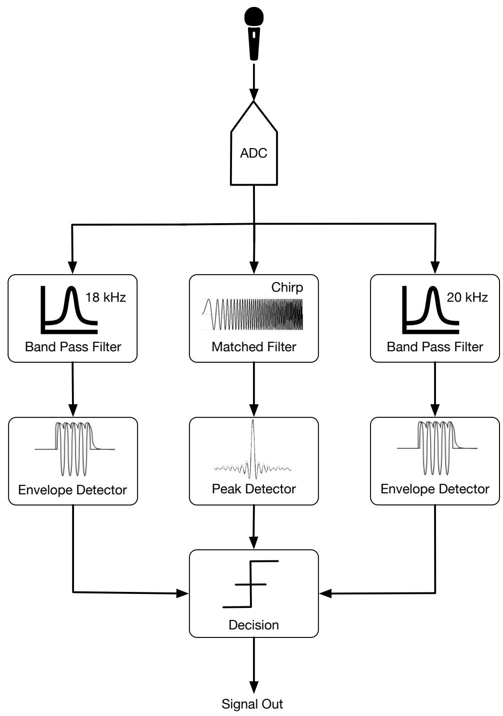

Fig. 2. Block diagram of the GUIMUS receiver (Non-coherent FSK demodulator)

III. Implementation and Preliminary Results

The practical implementation of the receiver described in the previous section has been performed on a Google Nexus 5 mobile phone, equipped with 2 GB of RAM memory and a Qualcomm Snapdragon 800 MSM8974AA processor. This phone incorporates the Android 6.0 Marshmallow operating system that allows the required 96 kHz sampling frequency. All signal processing is carried out off line, by first acquiring a number of samples high enough as to ensure the acquisition of two consecutive emissions (emission+gap+emission). This size guarantees that the emitted signal will be captured entirely inside the buffer at least once. All this programming has been conducted making use of the Android Studio SDK [22].

Fig. 3(a) shows an example of the actual signal acquired by the smartphone when placed at one meter distance from the tag emitting the 110011 code, and Fig. 3 (b) shows this signal after correlation with the chirp waveform.

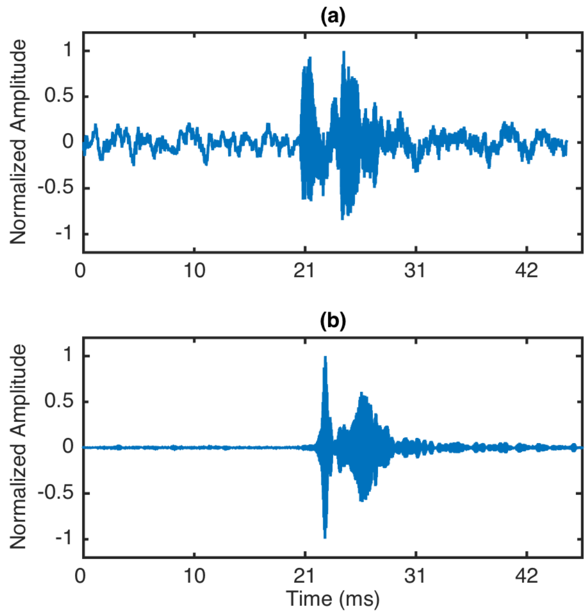

Fig. 3. (a) Actual signal acquired by the smartphone and (b) this signal after correlation with the chirp waveform.

Fig. 4 shows the output of the envelope detectors, that will eventually conduct to the detection of the 110011 binary stream. This code is transmitted to a central server that will provide all the information regarding the tagged exhibition through a WLAN link.

As stated before, one of the main features of the proposed scheme is the tolerance to Doppler shift of both, the chirp header and the BFSK modulated message. To illustrate this important property, we have simulated a Doppler shift on the actual signal represented in Fig. 3 (a), caused by a user moving towards the tag at a speed of 3 m/s. As demonstrated in previous works [20][23], this speed would have a dramatic effect on the detection of a pseudo-random sequence by matched filtering, making them completely unrecognizable to this filter. Fig. 5 shows that a clear correlation peak is still obtained at the matched filter output of the proposed system, and Fig. 6 shows that this shift has no effect on the demodulation of the transmitted FSK message, thus demonstrating the reliability of the proposed solution against this phenomenon.

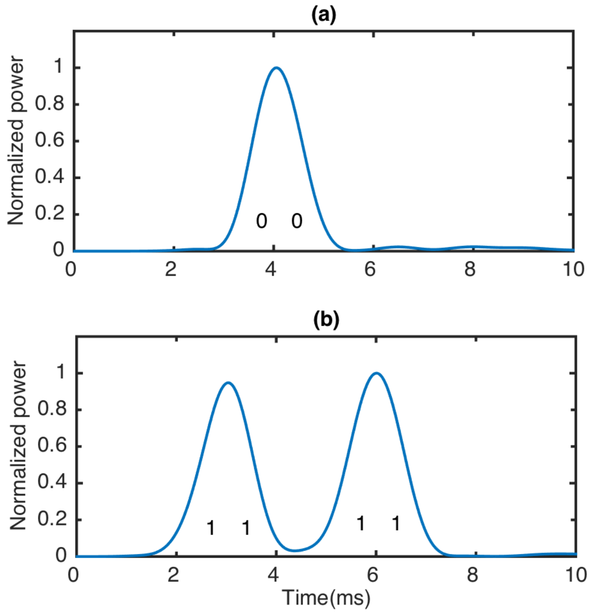

Fig. 4. Envelope detection after band-pass filtering at (a) f_0 = 18 kHz and (b) f_1 = 20 kHz.

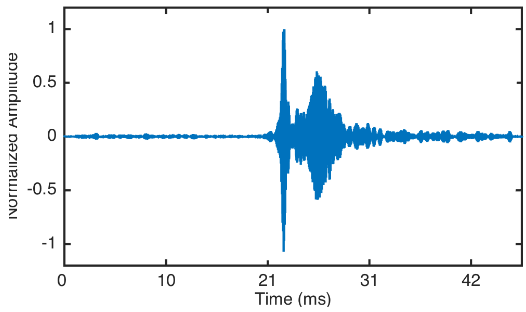

Fig. 5. Matched filter output for the signal received when the user is moving towards the tag at 3 m/s.

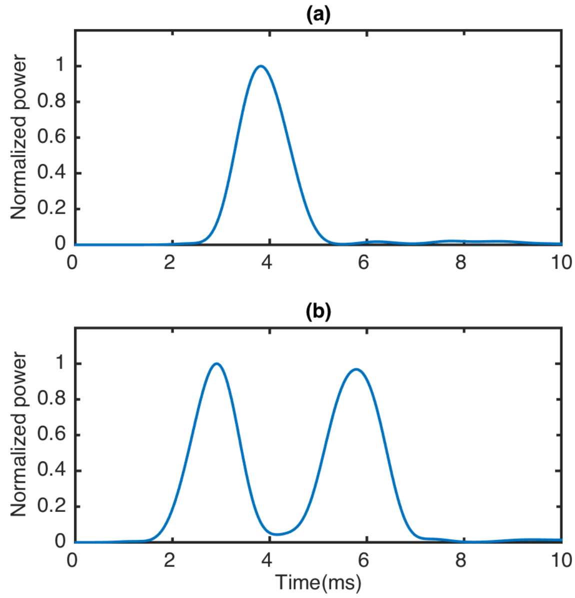

Fig. 6. Envelope detection after band-pass filtering at (a) f_0 = 18 kHz and (b) f_1 = 20 kHz for the signal received when the user is moving towards the tag at 3 m/s.

IV. Conclusions

This work has presented a smartguide prototype, based on the detection of high frequency acoustic signals with a mobile phone. One of the main novelties of this work is the use of an FSK communication protocol that ensures high tolerance to Doppler shift caused by the user's movement. Preliminary results show that the receiver architecture can be successfully implemented on an Android 6.0 based platform. This is, however, a work in progress, and further in-depth analysis must be conducted to characterize the system's performance. Maximum range, actual Doppler tolerance, angular coverage and system's behavior in crowded environments are some of the parameters that are currently under on-going study.

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