Aural Analysis Of The Harmonic Structure Of Sonar Echoes

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1. INTRODUCTION

The return echoes of many types of sonar systems from targets of interest (e.g., man-made objects such as submarines and sea mines) are often indistinguishable from non-targets. This is especially evident for low-frequency active sonar systems operating under conditions of substantial geological clutter. Geological clutter, or geoclutter, refers to strong coherent sonar returns from geological features on or beneath the seafloor, such as buried channels, found in a number of coastal regions. The failure to distinguish between targets and geoclutter results in substantially increased false alarm rates [1]. One approach towards addressing this problem is to use aural cues for distinguishing between the two classes of signals. Although not new, it is generally agreed in the sonar community that targets and geoclutter are often aurally distinguishable [2]. However, this is based primarily on anecdotal evidence and has yet to be formally analyzed.

An initial investigation was recently undertaken to identify aural properties of targets and non-targets that could explain their dissimilarities when judged by listeners. Using examples from real sonar data, auditory recordings of sonar echoes were decomposed into individual complex tones; each complex tone had a fundamental frequency (F0) and harmonics (i.e., a harmonic is an integral multiple of F0). Based on the strongest amplitude of the complex tones for each sonar echo, preliminary observations revealed that both classes of sounds differ little in F0, and targets have fewer higher order harmonics than non-targets. These observations suggest that timbre may be one attribute of auditory sensation that could account for the aural differences in the discrimination of these classes of sounds. Timbre is defined as that attribute of a sound that a listener can judge as different when two or more sounds have the same loudness and pitch [3]. For example, listeners can distinguish between a C4 note played on a trumpet from the same note played on a piano. We report on a pilot study that investigated the perceptual interactions between timbre and pitch; pitch is defined as the ordering of sounds on a musical scale [3]. Subjects were asked to rate the timbre of complex tones for different levels of pitch.

2. METHOD

2.1. Subjects

Two subjects with musical training and two with no musical training participated. The subjects with musical training had formal instruction in playing a musical instrument. All subjects self-reported normal hearing.

2.2. Stimuli and apparatus

Three pairs of complex tones were synthesized using the Cmusic program. The sounds were sampled at 48 kHz, and had a duration of 500 ms with a 10 ms onset/decay cosine envelope. The F0s for these pairs of sounds were 30 Hz, 40 Hz, and 50 Hz. Low frequencies were employed in order to vary the pitch, thereby allowing the F0s and their corresponding harmonics to span the frequency range of human audibility. The sounds in each pair had the same F0; for each pair of sounds one sound had harmonics 1-5, and the other had harmonics 6-10. Varying the spectrum of the sound via its harmonics provided a means of assessing timbre based on previous findings which showed that complex tones with strong harmonics below the 6th sound mellow, whereas complex tones with strong harmonics beyond the 6th or 7th sound sharp and penetrating [3]. All the F0s and harmonics had the same phase and amplitude. Testing took place in a quiet room that contained a personal computer, headphones, and chair.

2.3. Experimental design

There were 12 experimental conditions arranged as a between- and within-subjects repeated measures design. The between-subject factor was musical training. The within-subject factors were 2 harmonic patterns for each of the 3 pairs of sounds, and 6 variations of pitch. Pitch was varied by successively doubling the frequency of the F0s of the 6 sounds (i.e., combinations of 3 F0s and 2 harmonic patterns). Each frequency doubling raised the pitch by an octave on a musical scale. A block comprised the 6 sounds with pitch held constant.

2.4. Procedure

Subjects were individually tested. On each trial a sound was dichoticly presented over the subject's headphones. Subsequently, a rating scale representing a continuum from 0-100% appeared on the computer monitor. A rating of 0 denoted the sound was extremely mellow, and a rating of 100 denoted that the sound was extremely sharp. The subject's task was to rate the perceived timbre of the sound by moving the cursor (positioned by default at 50%), using the computer mouse, to the desired position on the rating scale followed by pressing the "enter" key. Each block contained 30 trials. The first 6 trials comprised 1 repetition of a random ordering of the 6 sounds. These were designated as practice trials and were intended as a means for the subject to become familiarized with the sounds. The remaining 24 trials comprised 4 repetitions of a random ordering of each sound. The presentation of blocks was in ascending order of pitch because a software bug prevented the randomization of the ordering of blocks. All the subjects participated in each experimental condition. The duration of the session was approximately 25 minutes.

3. RESULTS AND DISCUSSION

The practice trials were excluded from the analysis. The data were not statistically analyzed given that only 4 subjects participated. For both subject groups, the mean of the subjects' median ratings of perceived timbre for each sound in each block was calculated. The means were subsequently transformed to ranks; a rank of 1 indicates the sound having the highest sharpness. The judgement of timbre differed slightly between subject groups. For 5 of the 6 blocks, the sounds with harmonics 6-10 were ranked higher than the sounds with harmonics 1-5 which is in agreement with earlier findings [3].

These limited results suggest that subjects had no difficulty judging timbre. Musical training may thus not necessarily be advantageous in classifying targets and non-targets. The implications of the results obtained from the study on the perceptual interactions of timbre and pitch should help to further the understanding of the aural qualities that discern classes of sonar sounds, with the aim of leading to a reduction of false alarms. We emphasize that the present results are based on a pilot study and acknowledge that more work in this investigation is required.

4. REFERENCES

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