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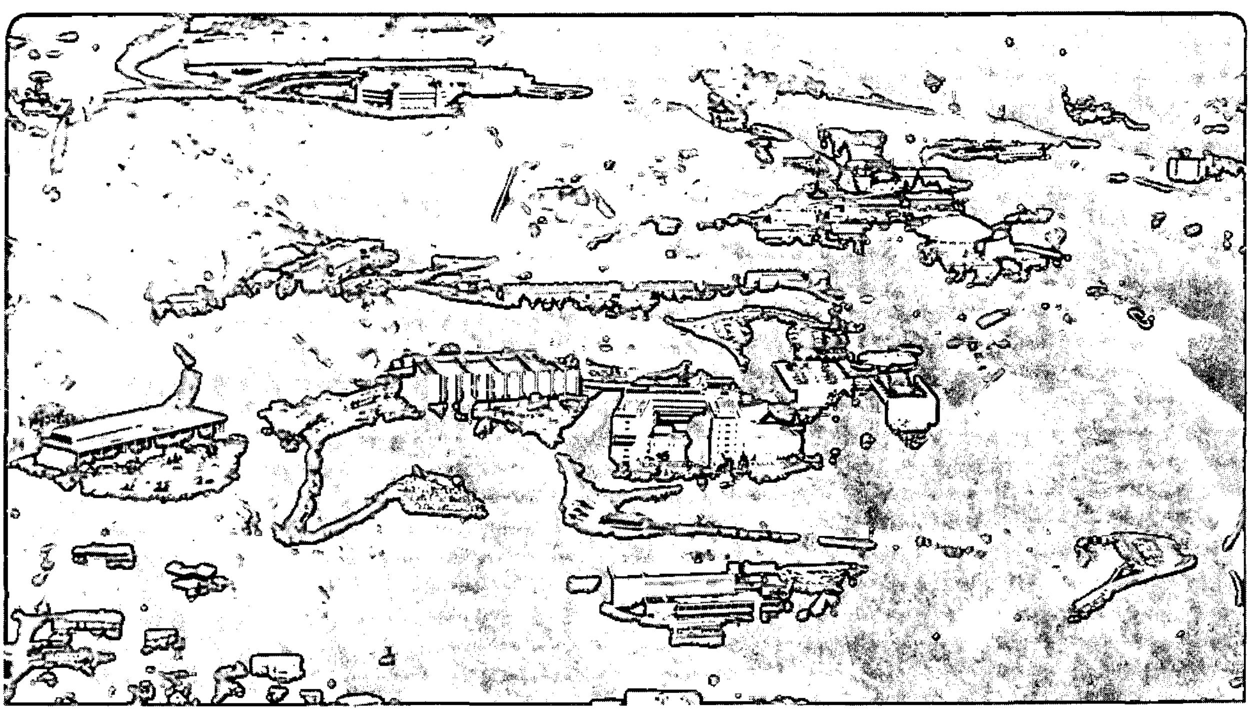

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Categorizing Sound for the Establishment of Source Characteristics

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ABSTRACT

An appropriate categorization of orthogonal parameters of naturally produced (not electronically synthesized) sound based on correlations between producer characteristics and parameters of the received signal can speed the unambiguous identification of the sources of received sounds. Orthogonal parameters of the received signal are the frequency content of its carrier, the amplitude of its envelope and time dependent variations of both. Natural sound sources are objects or cavities or fluids stimulated by modulating devices or rotating devices, or by rapid changes in temperature or pressure. In this paper, we attempt to relate the modulating device and its transmitting operand to unique distinguishing characteristics of the resulting sounds, and to categorize received sound characteristics in a way which permits unambiguous identification of the source.

INTRODUCTION

Figure 1 represents a sound-producer as a combination of an energy source, energy control mechanism, carrier generator and modulator. The modulator exercises control over the flow of energy from its source into the carrier generator. The carrier generator is a vibrating, rotating or other device for producing the high frequency carriers of a sound. Figure 2 illustrates some common carrier generators. If the resulting carrier has a strongly dominant fundamental frequency, it is most likely generated by some reciprocating system in a fluid (air). Resonant cavities, and resonant mass-spring systems (stiff or stretched objects) are reciprocating systems. A carrier with no strongly dominant fundamental frequency may result from turbulence in a fluid. Another class of carrier generators is rotating objects, such as windmills or engines.[1]

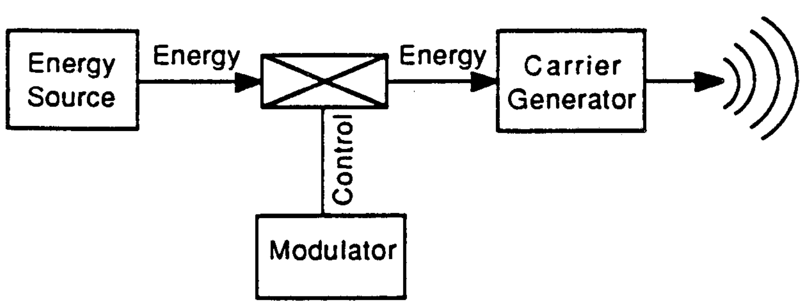

Fig. 1: The components of natural sound production are an energy source, a modulator and a carrier generator. The modulator controls energy flow to the carrier generator, resulting in carrier envelope variations.

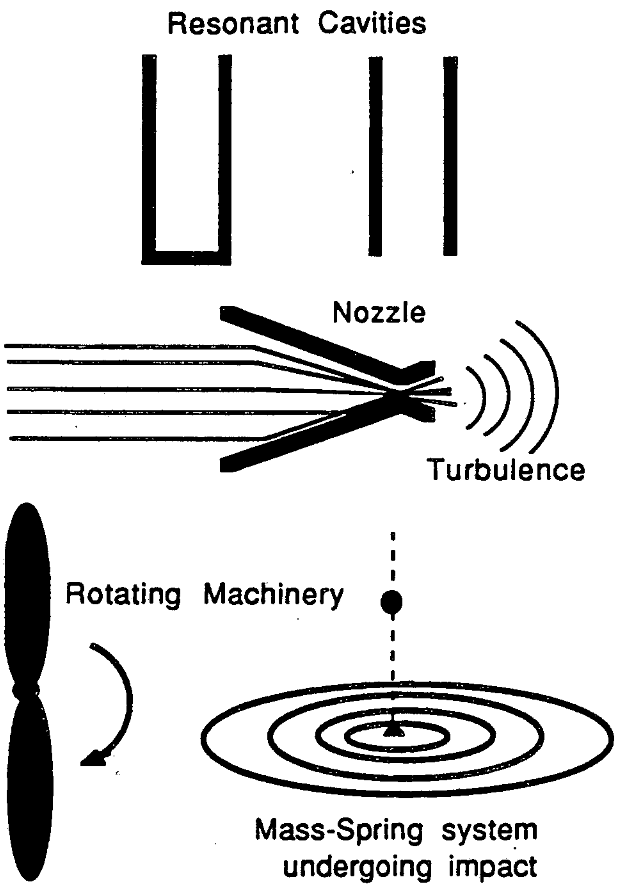

Fig. 2: Carrier generators produce the high frequency components of a sound. Rotating objects chop an air flow, producing "square waves", rich in even harmonics.

Modulators control the energy supply to the carrier generator. Energy delivery may be in the form of an air flow over a resonant cavity or through a nozzle; it may come in the form of a ratcheting which occurs when a rough object rubs across a resonant mass-spring system; or it may be heat generated inside a rotating engine. Energy delivery may be done by an object hitting a mass-spring system. As the controller of these processes, the modulator regulates volume and air flow direction, the speed of movement and position of a ratcheting mechanism, the fuel flow rate to an engine or the momentum of a hammer striking an object.

The modulator, by controlling energy delivery to the carrier generator, determines the carrier envelope. Intelligent modulators produce sounds with communicative intent. Benign modulations simply happen, as with lightning or wind-delivered impacts to resonant structures.

Sounds converging on any point may be visualized as originating from a surrounding soundscape [2] containing an assortment of carrier generators and modulators. Our intent is to devise categories describing received sounds in a way which uniquely identifies the type of modulator. Other questions may be answerable as well. What in the received sound will distinguish among resonant cavity, mass-spring, rotating system and turbulent carrier generators? Are characteristics of the energy source and of the energy delivery mechanism identifiable?

CATEGORIZING RECEIVED SOUND

Harmonic content can be used to help distinguish among carrier generator types. Figure 3 graphically represents the separation of four types of carrier generators based on harmonic content of the received sound.

- Rotating systems, dependent on sequences of explosions or on the chopping of a fluid flow, result in sounds containing an abundance of even harmonics.
- Resonant mass-spring systems depend on the generation of odd harmonics in order to radiate efficiently.
- The sound from a fluid in turbulence will usually contain a mix of harmonics, both odd and even.
- Fluid-column resonances will produce very few harmonics of either kind.

Harmonic content can be determined by an examination of the frequency spectrum of the received signal.

Modulators affect characteristics of the resulting sound in unique ways. The modulator, by controlling energy flow into the carrier, determines carrier amplitude, including the occurrence of periods during which carrier amplitude is zero (quiet intervals). Table 1 lists a few common modulators and labels some resulting sounds as "intelligent" or "benign". Generally, sounds having rapid variations in carrier amplitude or

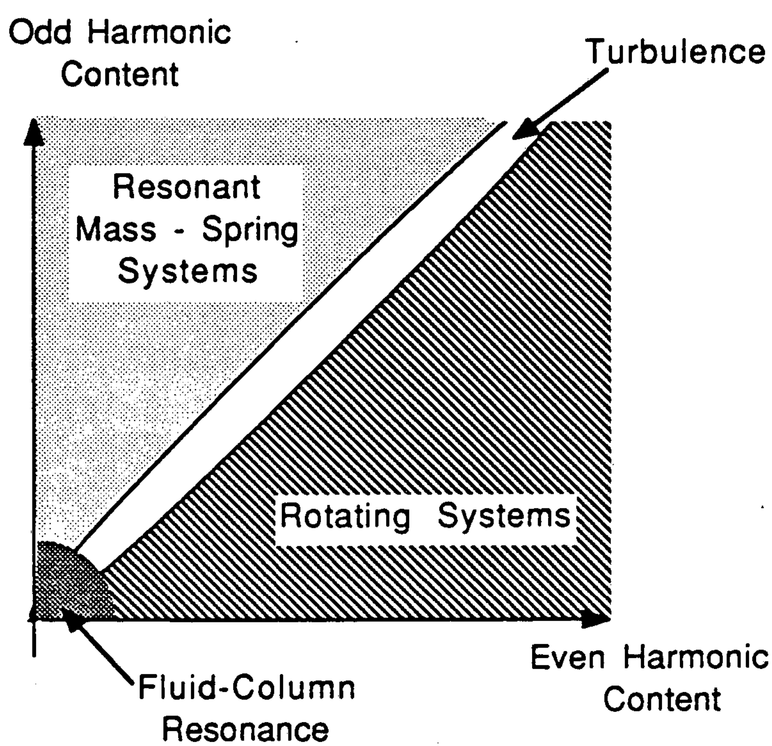

Fig. 3: Carriers may be classified in terms of their generators, and harmonic content of the resulting carrier may be used to help classify a received carrier. Efficient radiation from a resonant mass-spring system, for example, depends on the generation of odd harmonics. Air columns can produce carriers with few harmonics.

TABLE 1

MODULATOR	TYPE	ENERGY DELIVERY	CARRIER GENERATOR
Human	Intelligent or benign	fluid flow	pipes, rotating devices turbulent fluid
	Intelligent	ratcheting devices impacting devices	mass-spring mass-spring
Weather	Intelligent or benign	fluid flow	turbulence pipes mass-spring
	Benign	electric discharge	rapid temperature, pressure change
Animal	Intelligent Intelligent Intelligent or benign	fluid flow ratcheting impact impact	mass-spring mass-spring rapid pressure change mass-spring

A few examples of modulators showing possible energy delivery and carrier generators for each.

frequency and with irregular quiet spaces represent an intelligence-driven energy delivery to the modulator. Benign modulators produce simpler sounds with greater internal regularity.

In Fig. 4 sound types are shown occupying regions on axes representing lengths of quiet intervals, rate-of-onset of intervals of quiet, and regularity-of-onset of intervals of quiet.

Figure 5 defines the parameters of a received signal. The time-to-quiet-onset is the same as the carrier-envelope interval t_e. Rate-of-quiet-onset is derived by averaging the values of $t_{qo.m}$ and taking the reciprocal. Regularity-of-quiet-onset is the first moment of the values of $1/t_{qo.m}$.

Regions of the space defined in Fig. 4 define categories based on the quiet periods embedded in a sound as follows:

- Whistles - The origin point, representing uninterrupted carrier
- Buzzes - Sound carrier interrupted by short, high-rate quiets
- Phrases - Sound carrier possibly modulated both in amplitude and in frequency and interrupted by extended quiets
- Sound Strings - Sequences of similarly-modulated carrier interrupted by extended regular intervals of quiet
- Singularities - Single, short modulated carrier intervals surrounded by quiet

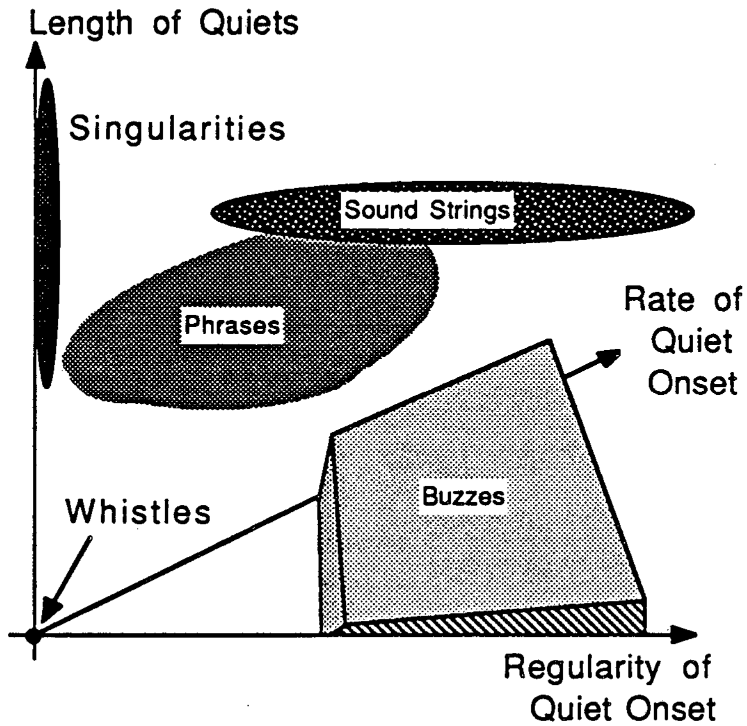

Fig. 4: Quiet, as it maps into a three-dimensional space, representing the length of quiet intervals, their regularity and their rate of appearance. Buzzes and whistles require steady energy delivery to the carrier generator. Singularities result from impacts or explosions. Whistles include the results of fluid turbulence, though they do not necessarily have any dominant frequency or harmonic content.

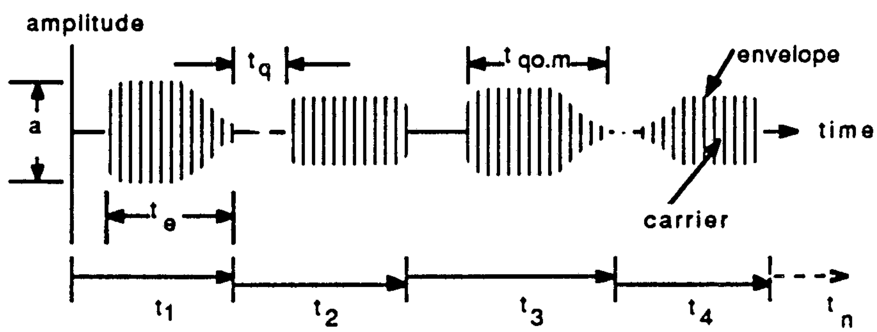

Fig. 5: Parameters of a received sound. The first moment of t_n is a measure of regularity-of-quiet-onset. The mean of t_n measures rate-of-quiet-onset.

Additional categorization may be done based on a description of the amplitude envelope, a of each carrier interval, t_e, as illustrated in Fig. 6. Carrier amplitude can either increase, decrease or remain steady during the interval of the carrier's duration.

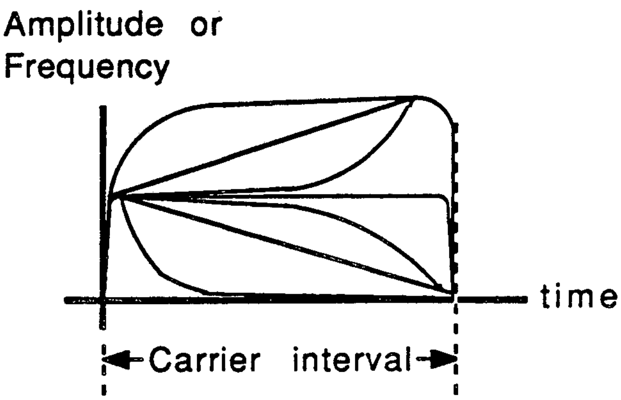

Fig. 6: Changes in carrier amplitude or frequency which might be expected during a carrier interval. Exponential amplitude decay may result from an impact delivered to a resonance. Rapid decay at the end of the interval may be due to exhaustion of the energy supply. A rapid increase in frequency at the end of the interval may indicate movement of the carrier source.

- A relatively constant carrier intensity points to a non-percussive source, such as air either in turbulence, or stimulating a resonant cavity.
- A percussive generator, such as a hammer striking a resonant device, would produce a decaying envelope. A steady decrease in amplitude may indicate the source is moving away from the receiver.
- An increasing envelope amplitude can mean an increasing supply of energy to the carrier generator, or it can mean a resonance is being pumped, or it can mean the generator is moving towards the receiver.
- A pumped resonance implies synchronization with the high frequency carrier, and the modulator is most likely a mechanized source.
- Complex envelopes occur as a result of intelligence-driven modulators.

Categories may be established based on the frequency characteristics of an interval of sound. The frequency may be steady, increasing, decreasing or complex over each carrier interval. A steady frequency is what would be expected from a fixed resonant source switched on and off by a modulator. Physical changes in the dimensions of a resonant chamber or physically changing the resonant chamber or changes in the parameters of a mass-spring resonant structure would produce frequency changes over one interval of the carrier, as would a moving source. The most likely source for frequency changes is intelligence-driven.

USING THE CATEGORIES

Following are some possibilities for use of the results. Once a sound has been characterized as to its:

a) harmonic content
b) quiet intervals
c) amplitude change within a carrier interval
d) frequency change within a carrier interval

we need a means of translating the characterization into a probability that the modulator is benign or intelligence-driven. A possible intermediate step is the identification of the carrier generator.

The four categories are orthogonal. Characterization within a category requires the development of methodology for assignment of probabilities to individual characteristics. The result will be four lists of probabilities.

Each list can be treated as vector components within a two-dimensional space defined by the axes 'benign' and 'intelligent' (Fig. 7). If individual modulators need to be identified, they may be thought of as occupying regions of the defined space, as shown. The resultant of the individual category vectors will lie at some point within the Benign-Intelligent space and its distance from each modulator's region can be used to determine the probability of that modulator generating the received sound. Other techniques for using the results of the sound characterization are possible. The described technique, with the addition of feedback-adjustable weights, will allow feedback to be applied with the intent of having the receiver improve its performance with experience.

CONCLUSIONS

Sound may be thought of in terms of a modulator controlling the energy flow to a carrier-generating device. By characterization of such sound within appropriate orthogonal categories, the potential exists for classifying the modulator as either benign or intelligence-driven. Characteristics of the carrier generator may also be derived from the results of sound characterization. One possible scheme for mapping the results of the sound characterization to a modulator is briefly described and embodies the potential for applying feedback with the intent of iterating to improve performance.

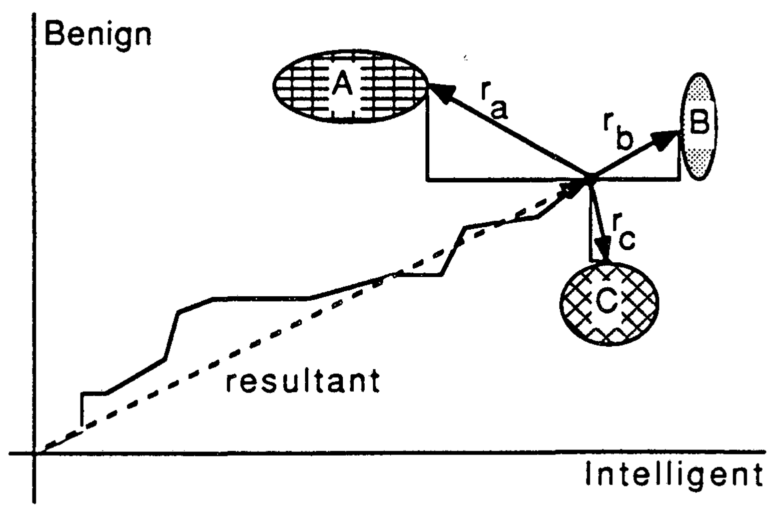

Fig. 7: In a modulator space, specific modulators can be thought of as occupying finite regions. Each characterization of an incoming sound produces short components of a vector, the resultant of which establishes a point in the modulator space. Selecting a probable modulator may be done by finding the closest modulator space.

ACKNOWLEDGMENT

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