EECS225d Audio Signal Processing in Humans and Machines **Spring 1995**

Lecture 3: January 23, 1995

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3.1 Readings for Wednesday

Please read pages 10-40 in Flanagan and the Stevens et. al. article "Electrical Analogue of the Vocal Tract."

3.2 Today

Today we will discuss the long history of the links that exist and existed between telegraphy and speech. In particular, we will discuss:

- That communication had a big influence on speech technology.
- The links between telegraphy and speech
- A brief history of optical and acoustic telegraphy.
- Bell's connection to Von Kempelen and Morse
- The music machines, science, and history from the time of Fourier until Mathews development of computer music.
- Dudley's [DT50] connection to Bell and Morse.
- Discussion of the Vocoder in WWII.

Speech science and technology is greatly influenced by the desire to communicate.

3.3 Telegraphy

Telegraphy is a very old method of communication, and it had a great influence on speech.

The main revolution occurred at the invention of the Morse code. Before that, however, there were other means of "telegraphy." For example, the ancient Greeks sent long distance signals by 1) flare, an optical transmission medium, and 2) voice, an acoustic medium where centurians with powerful voices would yell to each other from less than a mile apart.

In fact, a telegraphy path was found in what was once the city of Troy, now in Turkey. A flair transmission path existed from Troy to Argos, and theory believes that it only had about a 10 hour latency. In Aeschylus's Greek Tragedy, Agamemnon, there is a passage that describes such a path, although it could be apocryphal.

Roughly, the later history of telegraphy, or coded language in general, was as follows: In the 1600's, Bernoulli used a system of 5 bells to encode "text". IN 1670's, Morland used trumpet signals for a similar purpose, and bells were used in Swiss village churches to encode the meaning of a current event. Furthermore, the African tom tom drum was used to encode thoughts.

Speech traveled a similar path. In 1780, Von Kempelen invented his speaking machine, as did Wheatstone in the mid 1800's. Bell was directly influenced by Wheatstone, who was reputed to have copied Von Kempelen's speaking machine design through Von Kempelen's book. In fact, Bell, in 1875, was trying to figure out how to get more telegraph signals on the same line when he invented the telephone. Unfortunately, multiplexing was as yet not a mastered techniques, as photographs of Lower Broadway in 1887 show a tangled mass of dedicated phone lines.

Of course, we need bandwidth compression in the air-waves because of finite bandwidth. But as the above shows, we also need it for wire transmission just to reduce the number of wires necessary for transmitting a set of signals. Eventually, Dudley [DT50] invented the concept behind the voder and vocoder to help in doing speech compression. Charles Vaderson demonstrated the vocoder after WWII. A taped example of the vocoder shows that it can in fact represent a wide variety of speech sounds. This was extremely important technology as Churchill and Roosevelt needed (and did) communicate often during the war.

This history is also important for music and speech synthesis. In this, we begin to see the introduction of physical models. That is, we see:

- Acoustic tube modeling that resembles the vocal tract.
- Additive synthesis, Fourier coefficients of sine waves.
- Subtractive synthesis, begin with wide-band white noise or a wide band periodic signal such as a pulse train and filter it to get the desired spectrum.

Observe that pitch has been left out of this discussion at this time. We'll get to it another time.

3.4 History of Music Synthesis

Fourier introduced the concept of the spectrum. ¿From there, Helmholtz introduced the idea that the auditory system did a kind of spectral analysis. At the same time, Ohm suggested that timbre depends on the spectral magnitude. Around 1875, Edison invented the phonograph, and after that "stored sound" was possible, a revolutionary point in both speech and music. Around 1900, Cahull introduced the Telharmonium, an additive synthesis technique, and the later, Lev Termin introduced the Theremin a new musical electronic instrument. In 1948, Schaeffer did his Musique Concrete, the sampling of acoustically generated sounds and transforming them to produce new music.

In the 1950's, Max Mathews began working on digital computer sound synthesis, e.g., additive, subtractive, FM, non-liner, etc. He was partly motivated by BLODI, the Block Diagram Compiler, and went on to develop MUSIC-I, the first computer music programming language. The aims of this new music technology were many-fold:

- New Compositions
- Creative use of new sound capabilities
- High fidelity synthesis of acoustic instrument sounds
- To understand the physics of musical instruments.

3.5 More on the Vocoder

The Vocoder was invented in the mid 1930's. WWII began in 1939 and the USA entered in 1941. Consequences:

- Secure communication (including speech) became high priority
- Security implies greater transmission bandwidth
- Vocoder reduces necessary speech transmission bandwidth.

Consequently, a security system could then be developed to transmit speech within the limited bandwidth available. This was crucial for Roosevelt and Churchill who had many personal communications during the war.

Next time: More on physical models, the wave equation for a vibrating string.

References

[DT50] H. Dudley and T.H. Tarnoczy, "The Speaking Machine of Wilhelm Von Kempelen". *Journal of Acoustical Society of America*, Vol 22.