Week 3

Audio Analysis 2

Auditory System

- Ears, parts of brain, and neural pathways
- Changes in pressure move hair-like fibers within the inner ear
- Movements result in electrical impulses sent to the brain

Different parts of the ear resonate with different frequencies!

Critical Bands

- Thus, ear can be divided into frequency bands, called critical bands
- Each critical band responds to frequencies in its spectrum only

Critical Bands Properties

- Within a band, louder frequency can overpower quieter frequency
- Ear can create critical band centered on any audible sound
- Yet, Fletcher et al. came-up with some approximations

Critical Band	Center Frequency in Hertz	Range of Frequencies in Hertz	Bandwidth in Hertz
1	50	1-100	100
2	150	100-200	100
3	250	200-300	100
4	350	300–400	100
5	450	400–510	110
6	570	510–630	120
7	700	630–770	140
8	840	770–920	150
9	1000	920–1080	160
10	1170	1080–1270	190
11	1370	1270–1480	210
12	1600	1480–1720	240
13	1850	1720–2000	280
14	2150	2000–2320	320
15	2500	2320–2700	380
16	2900	2700–3150	450
17	3400	3150–3700	550
18	4000	3700–4400	700
19	4800	4400–5300	900
20	5800	5300–6400	1100
21	7000	6400–7700	1300
22	8500	7700–9500	1800
23	10500	9500–12000	2500
24	13500	12000–15500	3500
25	18775	15500–22050	6550

Tobias, J. V., ed. Foundations of Modern Auditory Theory. Vol. 1. New York: Academic Press, 1970

Perception of Intensity "Loudness"

- Higher intensity results in louder sounds
- Logarithmic with intensity
- Measured in decibels (db), 0 db represents hearing threshold

Decibel Scale

- Describes intensity relative to threshold of hearing based on multiples of 10

$$dB = 10 \log \frac{I}{I_0}$$

I_0 is reference level = 10^{-12} W/m^2

Decibel Levels of Common Sounds

Sound	Decibels
Rustling leaves	10
Whisper	30
Ambient office noise	45
Conversation	60
Auto traffic	80
Concert	120
Jet motor (Discomfort)	140
Spacecraft launch (Pain)	180

Perception of Frequency is Pitch

- Higher frequencies perceived as higher pitch
- Frequency changes by multiplication, pitch perception changes by addition
- The perception of pitch can vary with intensity

Three Sounds with the Same Pitch

Timbre

Timbre is that attribute of auditory sensation in terms of which a listener can differentiate between two sounds having the same loudness and pitch!

Timbre Properties

- Complex patterns added to the fundamental frequency of a sound
- Spectra enable us to distinguish musical instruments
- Multiples of fundamental frequencies give music
- Multiples of unrelated frequency gives noise

Physical		Psychoacoustic
Intensity	≈	Loudness
Frequency	≈	Pitch
Spectrum	≈	Timbre

Pitch Range

- Lowest for males – 60
- Highest for children's – 800 Hz
- Male Pitch ~125 Hz
- Female Pitch ~225 Hz

How to calculate pitch?

Pitch perception is subjective, cannot be measured from sound alone!

Pitch detection measures the fundamental frequency of the sound as an approximation to the pitch!

Pitch Properties

- Can be perceived even when the fundamental frequency is absent
- The ear intelligently fills the fundamental frequency, low quality radio

Pure Tone

1 to 10 Harmonics

4 to 10 harmonics

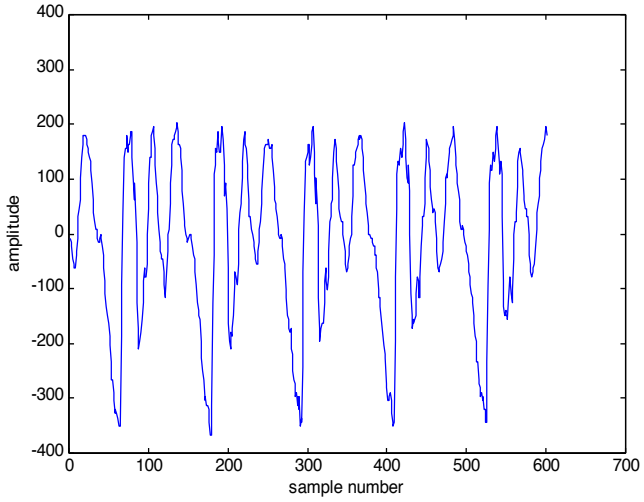
Methods

1. Frequency-domain

2. Time-domain

Time-domain pitch estimation

- Variations of fundamental frequency are evident
- Time-domain speech processing should be capable of detecting pitch frequency

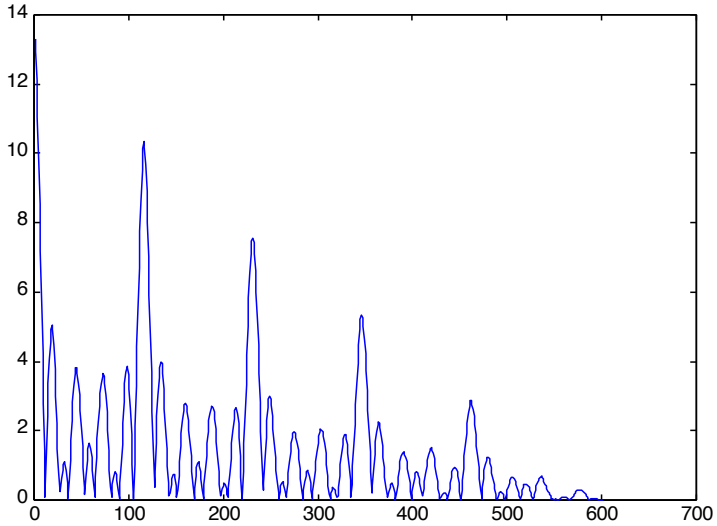


Pitch Period Estimation Using the Auto-correlation Function

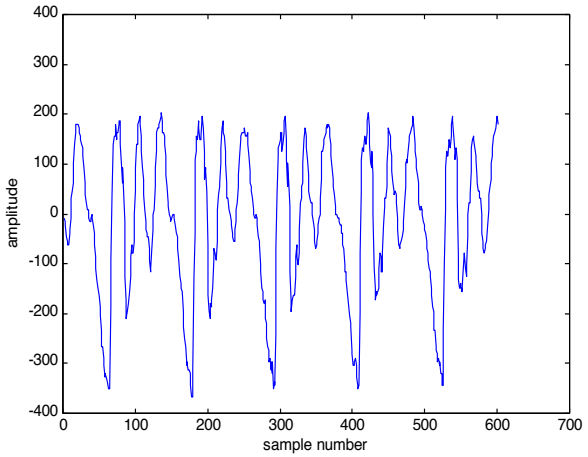
$$R_{xx}(k) = \sum_{n} x(n) * x(n+k)$$

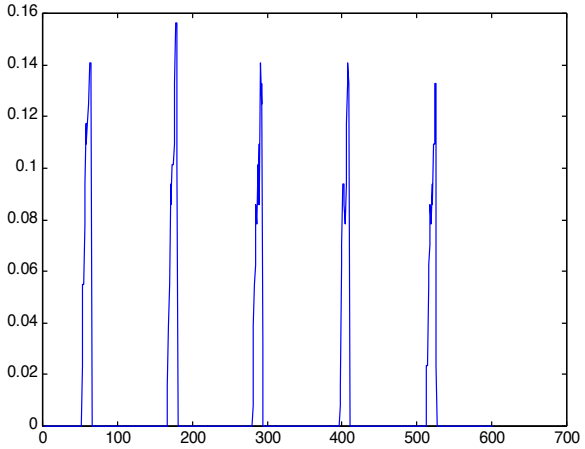
Observation:
Periodic signals have periodic auto-correlation function!

Auto-correlation function has *many peaks*



"Spectrum flatteners" techniques





Steps

1. Perform autocorrelation on samples
2. Locate peaks and calculate the average period
3. Pitch = Fs / ave. period

Improving Pitch Detection

- Low pass filtering
- Spectral flattening
- High resolution spectral analysis