Digital Signal Processing and the Rise of Consumer Electronics

IEE History of Technology
Professional Network Launch
University of Birmingham 5 July 2002

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Abstract

Consumer electronics first appeared in the 1920s with large sales of radios and electronic phonographs. The transistor, beginning in the 1950s, and the integrated circuit, beginning in the 1960s, led to many new and improved consumer products, such as the shirt-pocket radio and the handheld calculator. By the end of the 20th century, consumer electronics had become a major sector of the world economy with a wide range of products such as camcorders, televisions, video and DVD players, video games, audio equipment, "smart toys", fax machines, cell phones, answering machines, GPS systems, PDAs, and desktop and laptop computers. An easily overlooked but vital factor in the rapid growth of the field has been digital signal processing. Signal processing may be defined as the purposeful changes made to signals so as to improve transmission or use of the signals, and though this branch of engineering remains unknown to most people, many of its tasks—such as analog-to-digital conversion, error-correction coding, speech synthesis, and image compression—have become familiar. The techniques of digital signal processing, from the 1960s to the present, have played a large role in the remarkable expansion of consumer electronics.

Definition of 'signal processing'

- The changes made to signals so as to improve transmission, storage, or use of the signals.
- Processes such as filtering, coding, estimating, detecting, analyzing, recognizing, synthesizing, recording, and reproducing.

Signal processing engineers are concerned with the signals themselves (as typographers are concerned with the choice and arrangement of type).

Most, but by no means all, signal processing falls into one of two classes.

Speech and music processing

- Analog-to-digital conversion
- Compression
- Error-correcting codes
- Multiplexing
- Speech and music synthesis
- Coding standards such as MP3
- Interchange standards such as MIDI

Image processing

- Digital coding
- Error correction
- Compression
- Filtering
- Image enhancement and restoration
- Image modeling
- Motion estimation
- Coding standards such as JPEG and MPEG
- Format conversion

Analog signals

continuously varying values

Digital signals

finite set of permissible values
(often just two values, 0 and 1)

crucial advantages:

- *exact transmission, storage, and reproduction possible*

Whatever the noise level in a transmission or recording system, we can make the signals for 0 and 1 sufficiently different that one cannot be mistaken for the other.

- *signals easily manipulated*

Almost any conceivable manipulation can easily be programmed: mixing signals, encrypting signals, filtering signals, and so on.

The Haas effect

If the same sound reaches a hearer from two sources at nearly the same time, the hearer will perceive the sound as coming from the source whose sound reaches the hearer first, *even if the volume of sound is greater from the other source*.

An improved PA system

The Haas effect was used to make an improved public-address system.

A full signal-processing sequence

An analog signal is passed through a low-pass filter (also called an anti-aliasing filter), the subjected to sample-and-hold, then quantized to yield a sequence of 0s and 1s. After some DSP task, the steps are reversed. The DSP might be multiplexed transmission, or error-correcting coding, or removal of brackground noise from an old recording, or false-color rendering of a photograph to bring out otherwise invisible differences, or compression of a video signal for streaming over the Internet.

The CD player provides an example of such a sequence.
• spiral path with pits or "dimples" (the falling and rising edges of a dimple correspond to the falling and rising edges of the pulse train); where there is a height change the laser beam is not reflected sharply; a light sensor recreates the sequence of 0s and 1s, which is converted back to an analog sound signal
• 44,100 samples per second, each sample represented by 16 bits, so 74 minutes of music 3.1 billion bits, error correction and other coding requirements multiply that by 3
• increased bandwidth (lower bound of 20 Hz rather than 30 Hz), flatter frequency-response curve, greater dynamic range (90 dB rather than 70 dB), better signal-to-noise ratio, and much better separation between the two stereo channels
• in less than a decade from their introduction in 1982, CD players drove record players off the market

Analog signal processing

- application specific
- there does not exist a discipline of analog signal processing

Digital signal processing

- transferable techniques
- the discipline of DSP emerged in the 1970s

triggering events: FFT and microprocessor
• FFT (1965 by John Tukey and James Cooley): a much faster way to determine the frequencies present in a signal (standard operation)
• microprocessor (1971): computer on a chip, computing power at low cost

DSP is today a major branch of engineering; there are some 50,000 DSP engineers.

Traditional electrical engineering
making electrons flow in conductors
generators, motors, lights, heating elements
Electronics
making electrons flow through vacuum, gas, or semiconductor
electron tubes, transistors

Consumer electronics
electronic devices sold for personal use

In 2001 the U.S. consumer electronics industry was a $96 billion business (hardware alone). Sony consumer electronics had annual sales of $65 billion worldwide recently.

A brief history of consumer electronics, looking at the most important new products decade by decade and commenting on the underlying technologies, is now presented.

Consumer electronics: The 1920s
Consumer electronics is born.
- radio receivers
- electric phonographs

Consumer electronics: The 1930s
- car radios

By the end of the decade 20% of all cars had factory-installed radios; Motorola was the largest manufacturer.
- portable radios

Attempts to market portable radios were made from the mid 1920s on. There was a boom in sales in the late 1930s in England (a sensible purchase with war threatening), which caught the attention of U.S. manufacturers.

Consumer electronics: The 1940s
- the LP and the 45
- hi-fi equipment (putting together one's own sound system: amplifier, speakers, tape recorder
- black-and-white television

Consumer electronics: The 1950s
- tape recorders
- transistor radios
- hearing aids
- stereo records

Notice that two of the new products used transistors (up to this point, all electronics products used tubes).

Consumer electronics: The 1960s
- the audio cassette (Philips 1963, also 8-track audio 1965)
- color television (introduced in the mid 1950s but few sales and little programming until the 1960s)
- VHF/UHF television

Integrated circuits were beginning to be used.

Consumer electronics: The 1970s
- pocket calculators
- video games (1972 for play with TV receivers, 1976 microprocessor video games)

- Walkman (Sony 1979) -- personal electronics
- video cassettes (Beta and VHS)
- CB radios

There was a transition to digital in the 1960s, though not yet consumer electronics. The T-1 carrier system (1962) was the first common carrier digital communications system (8000 samples per second, 7-bit representation). Consumer electronics began to become digital in the 1970s, with calculators and video games, also Speak & Spell (voice synthesis).

Consumer electronics: The 1980s

- CD players
- fax machines
- personal computers
- camcorders (1980) (portable camera-VCR combinations)
- electronic toys
- modems
- mobile phones (1983 cell phone service in U.S.)]

Notice that most of these devices are digital.

Consumer electronics: The 1990s

- laptop computers
- PDAs
- digital cameras
- digital camcorders
- DVD players
- home theater systems
- direct broadcast system receivers
- GPS systems
- MP3 players

Notice that all but one of these products are digital.

Consumer electronics: 2000 - 2010

- HDTV
- electronic books
- satellite radio
- electronic devices that communicate without wires
- noise cancellation
- car-navigation systems
- personal medical devices (heart-rate monitors, blood pressure monitors, glucose monitors (using near-infrared transmitted through tissue))

Notice that all of these products are digital.

Every single product listed on these transparencies, from the 1920s to the present decade, involves signal processing, simply because consumer-electronics devices are for communication, entertainment, or some other type of information processing, and the information is carried by electrical signals or one form or another. (This is in contrast to consumer electrics, where some physical effect, such as toasting a bagel or dicing carrots, is the objective.)

Until the 1970s all of the devices listed were analog, so although signal processing was certainly involved, it was done by radio or TV engineers or audio engineers – there was no discipline of signal processing then. Beginning in the 1970s with calculators and video games, digital electronics has replaced analog electronics, and almost every device listed for the 1980s, 1990s, and the present decade is digital, so almost every device involved digital signal processing.

The DSP chip

Single-chip digital signal processors

- first appeared in the early 1980s
  Texas Instruments TMS32010,
  AMI S2811, Intel 2920, NEC muPD7720
- specialized for types of processing
  audio: Motorola 56000
- specialized for particular tasks
  tapeless answering machine, voice recognition

DSP algorithms may be implemented on microprocessors or microcontrollers, but the major impact of DSP on consumer electronics is through so-called DSP chips.
There are general-purpose DSPs, ones that have been designed for types of signal processing (such as for audio (the Motorola 56000, introduced 1985) or for digitized imaging), and ones for particular tasks (such as for tapeless answering machine or for speech recognition).

One example of a DSP chip is one for speech recognition (for cell phones and other telephones, clock radios, MP3 players, TV remotes, light switches, and toys (such as robotic dogs)). The first consumer product with speech recognition was the 1987 Julie doll (turned her head when her name was spoken). There are now 100 million in use (85 million for cellphone voice dialing, 15 million in other devices. Until recently they cost $20 a unit, now $1 for the RSC-364 from Sensory, so that manufacturers add it as a gee-whiz component.

Many of the devices listed for the 1980s and almost all of the devices listed for the 1990s and the present decade incorporate DSP chips.

Computer architectures

• von Neumann architecture: almost all computers, only one thing done at a time (von Neumann bottleneck)

• Harvard architecture: allows a program instruction and a data word to be accessed simultaneously (so the data flow does not need to be interrupted for instructions to be read)
Many consumer-electronics devices require real-time processing.

Advantages of the DSP chip
• a dedicated multiplier unit so multiplication is carried out in a single cycle (not, as in traditional processors, through a series of shift-and-add cycles)
• special instructions that are carried out in a single cycle, such as multiplying two numbers and simultaneously adding the previous product (multiply-accumulate operation)
• multiple-access-to-memory architectures (several data words retrieved in a single cycle)

Co-evolution of algorithms and chips.
• not only was the hardware designed with DSP in mind, but also new algorithms for particular tasks were designed for the hardware capabilities of DSP chips

The result: DSP chips carry out DSP algorithms faster than microprocessors by an order of magnitude or two.

What difference has DSP made for consumer electronics?
- It improved many products.
  camcorders, answering machines
- It made some products possible for the first time.
  digital cameras, talking toys
- It made many products less expensive.
  video games, cell phones
- It created large markets through standardization.
  media formats, interchange formats

One might ask also what difference has consumer electronics made for DSP. The answer is obvious: a major sector of the economy exploits the techniques and latest advances of DSP, and DSP is a large and still-growing branch of engineering, and one becoming known to the public in general.

Historical trends
- Continual increase in the number and popularity of consumer-electronics products
- Replacement of tubes by solid-state devices
- Replacement of analog circuits by digital circuits
- Great increase in the use of DSP chips