Boundless Security Systems, Inc.

sharper images with better access and easier installation

Tutorial: Fundamental Principles Behind Digital Video Security Systems

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Analog Video Standards

- NTSC
- Effects on CCTV Cameras

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NTSC, a 50-Year-Old Handicap

- Analog video signal protocol used by all CCTV video cameras and monitors in USA ***fundamentally limits video image quality of all CCTV systems and surveillance systems***
- Analog video signal sensitive to noise
- Vertical resolution limit 480 lines
- Horizontal resolution limit 704 to 720 pixels
- Color resolution only 1/2 of brightness
- Each "picture" (frame) requires two fields

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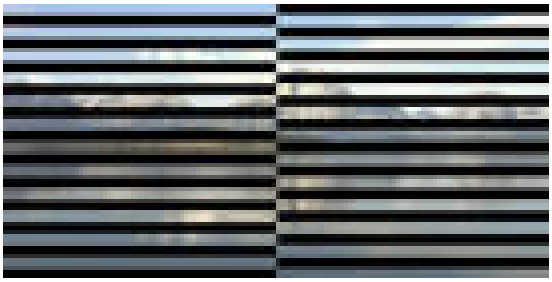
NTSC, a 50-Year-Old Handicap

- Two interlaced fields per frame reduce video monitor flicker but blur motion capture
- Color image sensors blur images even more

Each frame is formed from two interdigitated fields over a fixed period of 1/30 second.



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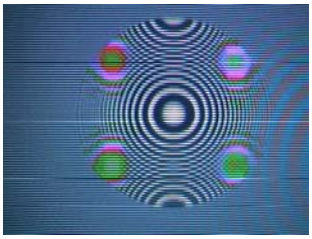
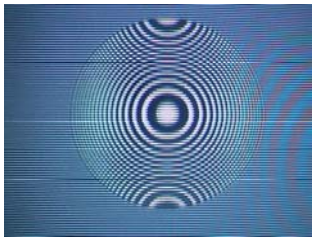
NTSC, a 50-Year-Old Handicap

- Color and brightness information in a single composite video signal interfere with one another, smearing and blurring images



Color fringes in inferior composite video (NTSC)



No fringes in component video (not NTSC)

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CCTV Video Camera Handicaps

- 35 mm camera typically uses 1/125 s exposure to freeze motion but CCTV camera whole-frame exposure usually fixed at slow speed of 1/30 s (PAL: 1/25 s)
- Faster CCTV video exposure, e.g., 1/1000 s, applies only ***line-by-line*** not to whole frame
- Maximum whole-frame exposure only 1/60 s (not 1/30 s), limiting use in dim light
- Poor exposure control with slow response to rapid changes in lighting; night problems

Image Sensors

- Types of Sensors
- Color Capture
- Exposure Problems
- Motion Capture

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Types of Image Sensor Chips

- **CCD's** -- Charge Coupled Device, oldest but common image sensor technology, lowest noise; need multiple chips for digital output, higher power and more expensive than CMOS due to special manufacturing
- **CMOS** -- Complementary Metal Oxide Semiconductor, only single chip required for digital output, same mainstream manufacturing as many logic chips for low cost, lower power than CCD's

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Color Capture Technology

- RGB color filters, one for each of 3 image sensors, beam splitter -- expensive, fragile
- Stacked color-sensitive silicon layers in sensor -- promising but unproven
- RGB color filter dots in hexagonal pattern, must convert to composite colors
- RGB color filter dots in rectangular pattern (Bayer 2G) are most common but must be converted to composite colors (YUV) for compression or use as NTSC video signal

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Image Sensor Exposure Problems

- Limited image contrast
- Details in shadows and highlights lost
- Interlaced scan limits maximum exposure to short field period, 1/60 s, limiting night use
- Fast exposure line-by-line not whole frame
- Built-in exposure adjustment easily fooled by dark background and bright moving objects, and rapid changes in brightness, can't capture license plates at night or eyes behind dark glasses

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Image Sensor Color Capture Problems

- Significant processing power needed for color conversion
- Many sensors have simple built-in ability to convert 2-D patterns of dots so external hardware not needed but sharpness lost and artifacts created, especially with moving objects

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Image Sensor Color Capture Problems

- 2-D regions of dots (pixels) are converted to brightness (Y) and color (U, V) for CCTV cameras and digital image compression
- Motion artifacts created because two lines in two fields used to convert pixels

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NTSC Motion Capture Problems in Image Sensors

- Interlaced scan takes two pictures (fields) starting 1/60 s apart to make a frame
- Moving objects are in different locations due to time differences between scans
- Size of moving objects distorted depending on direction of travel relative to scanning
- Severe problems if camera not steady
- ***Two*** sources of blurring, not just one -- use of two lines from each of two fields

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NTSC Motion Capture Problems in Image Sensors

- Objects move and are captured during ***entire*** 1/30 s frame (two fields) period
- Filter dot pattern requires combining of pixels from ***both*** fields into ***each*** field
- Interlace requires doubling of height of pixel blocks for motion estimation, key part of video compression, reducing video compression ability because likelihood that pixels are from same object reduced
- Alleviated in frame-store transfer CCDs

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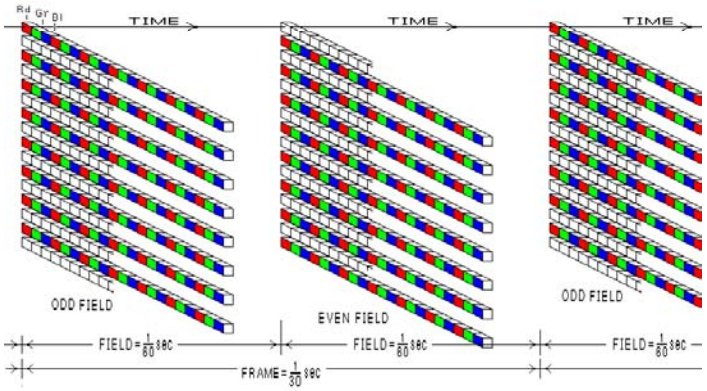
NTSC Motion Capture Problems

- Odd field is RGRG, even field GBGB...



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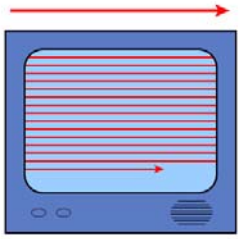
Progressive Image Scanning -- Superior to Interlaced

- Entire image scanned only once per frame
- Still digital cameras use it
- Motion pictures, HDTV and high-end DVD players and video displays use it to give sharpest images
- Captures motion better
- Video compresses better
- CCTV cameras can't use it
- Motion pictures 24 fps not 30



Video Compression

- Standards
- Data Rate Control
- Data Rates
- Factors in Video Quality
- Amount of Storage Required

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Video Compression Standards

- **MJPEG** - Motion JPEG, each frame compressed separately using many small blocks of pixels, creating many artifacts, high quality images if compression < 10:1
- **Wavelets** - each frame compressed separately but as a whole, fewer obvious artifacts than JPEG, high quality if compression < 10:1, better than JPEG at very high levels
- **H.261** - uses motion estimation, early video conferencing standard, better than JPEG

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Video Compression Standards

- **MPEG-2** - uses motion estimation -- static information sent infrequently, differences between adjacent frames are compressed using small blocks of pixels; high quality compression < 30:1 (used in DVDs)
- **MPEG-4** - similar to MPEG-2 but compares more frames to give more compression; high quality compression for entertainment video < 100:1; problems with rapid changes in camera angle, zooms, fades

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Video Compression Data-Rate Control

- **Constant bit rate (CBR)** - encoder limits bit rate for real-time communications channel with limited bandwidth, sacrificing image quality when high motion or detail, produces fixed (high) data rate even with static image
- **Variable bit rate (VBR)** - encoder allows bit rate to vary widely, including to near-zero in absence of motion, very useful for security and surveillance applications because storage needs are reduced automatically

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Video Compression Data Rates

- Measure raw color video as 24 bits/pixel
- Raw broadcast-quality data rate = 24 bits/pixel x 704 pixels/line x 480 lines/frame x 30 frames/s = 243 Mbps (Million bits / s)
- MJPEG: 10:1 => 25 Mbps (DV cam)
- MPEG-4 VBR (e): 100:1 => 2.5 Mbps
- MPEG-4 VBR (s): 1,000:1 => 0.25 Mbps

➔ *Better compression => higher frame rate, better images and longer storage*

(e) = entertainment content, (s) = security content

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Video Compression Data Rates

- MJPEG @ 25 Mbps = 3 MB/s => 5.5 minutes / 1 GB storage
- MPEG-4 VBR (e) = 0.3 MB/s => 1 hour / 1 GB storage
- MPEG-4 VBR (s) = 0.03 MB/s => 10 hours / 1 GB storage

➔ *MPEG-4 VBR gives up to 100x improvement over MJPEG for security video, enabling more and better images to be stored, longer*

(e) = entertainment content, (s) = security content

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Benefits of Video Compression with MPEG-4 VBR vs. MJPEG

- Increase frame rate up to 100x for given image resolution
- Reduce data storage up to 100x for given image resolution
- Better compression is much less expensive than more hard drives
- Much smoother video wirelessly, where transmission speed is limited

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Factors in Video Quality

- Resolution of each image - ***easily measured***
- Color depth and format
  - typ. 8 bits per value
  - color or monochrome
  - sharpness of brightness typ. different than color
  - YUV411: color has 1/4 sharpness of brightness
- Frame rate - ***easily measured***
- Clarity of each image - ***hard to measure***
  - hard to quantify and depends on content
  - depends upon amount of in-frame compression

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Factors in Video Quality

- Basic measurement for one camera
  - DEFINE: Video Quality = Resolution x Frame Rate
- Use standard units for resolution
  - CIF = 320x240 (computer) or 352x240 (TV)
- Examples: Video Quality =
  - 1 CIF x 4 frames/s = 4 CIF/s *(many DVR's and PC-based digital video recording systems)*
  - 1 CIF x 30 frames/s = 30 CIF/s
  - 4 CIF x 30 frames/s = 120 CIF/s is required for full quality, standard definition NTSC

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New Unit of Mass Video Storage

- Must think on a much larger scale to store massive amounts of compressed video
- Proposed new storage unit = 1-1-1-1
  - 1 continuous (24/7) video stream at...
  - 1 million bits per sec. (Mbps) continuously for...
  - 1 quarter of a year requires...
  - 1 terabyte (TB = 1,000 GB = 10^6 MB) of storage
- Example
  - Large airport with 1,000 cameras 24/7 for 3 months at 1 Mbps/camera continuously requires 1,000 TB

Wireless LANs

- Types
- Problems

Wireless LANs

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- Digital LAN is different from "X10" wireless transmission that only sends analog signals
- Common high speed wireless LAN standards
  - 802.11a: speed to 72 Mbps at 4.8 GHz
  - 802.11b: speed is 1 to 11 Mbps at 2.4 GHz
  - 802.11g: speed is 1 to 54 Mbps at 2.4 GHz
  - Note: Usable payload is only about 50%
- Like old coax LAN, not switched LAN, efficiency drops as number of users increases due to collisions between their data

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Wireless LANs

- No FCC license required but microwave ovens, wireless phones and other devices can interfere with transmission / reception
- Can be jammed by too much traffic, either accidentally or by local Denial-of-Service; must protect main network from overloads
- Multiple sets of frequencies/channels add capacity, but most overlap one another
- ***Much harder to use than it appears due to signal absorption, reflection, interference***

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Wireless LANs

- Example of problem
  - A dense wall with a wireless node on each side, node is far from the end of the wall
  - Wireless Access Point beyond the end of the wall, can communicate with both nodes
  - Problem: Wireless nodes may not be able to communicate with each other and therefore jam each other's signals at the Wireless Access Point since one node doesn't know when the other node is sending

Internet Protocols for Video

- HTTP
- File Transfer
- Streaming

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HTTP: Hyper Text Transfer Protocol

- Common “language” of Web pages
- Reliable, two-way communication with user
- Does not directly support dynamic data
- Network cameras act as Web servers, commonly used due to simplicity of software
- Web server stores “video” as series of JPEG files, which are updated as often as possible
- Each file stores one frame of an image
- Each file must be closed to be accessed

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HTTP: Hyper Text Transfer Protocol

- Web browser has Java program that reads, decodes and displays each new JPEG file
- Low frame rate due to synchronization problems and slow speed of Java, which does not use microprocessor-specific speedups for image decoding or converting YUV video to RGB for PC's video display
- Each viewer generates more work for network camera and its network segment, potentially overloading them

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FTP: File Transfer Protocol

- Complex protocol used to move files
- Reliable, two-way communication with user
  - Packets can be received in any order
  - Missing or damaged packets are resent
- Files must be closed to be moved
- Complex data rate control optimizes rate of data transmission to speed of network
- Efficient - single acknowledgement for many packets reduces overhead

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TFTP: Trivial File Transfer Protocol

- Simple version of FTP, used to move files
- Reliable, two-way communication with user
  - Packets can be received in any order
  - Missing or damaged packets are resent
- Files must be closed to be moved
- No data rate control to optimize rate of data transmission to speed of network
- Inefficient - single acknowledgement for each packet is required

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RTP: Real Time Protocol

- Unreliable, one-way broadcasting of live and recorded audio and video to multiple users
- Like a TV or radio station -- information is sent once and continuously without regard for any transmission or reception problems
- Less network and server traffic than FTP and TFTP since no acknowledgements used
- Packets can be lost for several reasons
  - Transient network overloads or insufficient speed
  - Transient receiver and server overloads

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RTP: Real Time Protocol

- Any error affects many frames when highly compressed video, MPEG-4, is used, since most frames are built from previous frames
- Endless stream of data must be decoded and broken into files for recording by receiver, burdening receiver
- Finite packet size limits number of users to which media can be streamed
- Streaming server must receive updates to add/remove recipients from multicast list

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The End

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