Why is sports photography hard?
(and what we can do about it using computational photography)

CS 178, Spring 2014

Marc Levoy
Computer Science Department
Stanford University
Sports photography operates at the edge of current camera performance and portability.

Computational techniques might be able to help, but it won’t be easy.
What this talk is about

- sports, especially team sports on fields or in arenas
- what is challenging about photographing these sports
- the affordances and limitations of today’s cameras
- opportunities for computational photography
What this talk is not about

✦ technical photography
  • e.g. finish-line slit photographs

✦ sports photography using point-and-shoot cameras
  • shutter lag makes it almost impossible

✦ non-sports action photography, family & recreation
  • harder to generalize about

✦ sports videography
  • except to the extent video could help still photography

✦ making every shot count
  • that’s impossible; goal is to improve from 1 in 100 to 10 in 100

✦ once-in-a-lifetime shots
  • you can’t plan for them
Once-in-a-lifetime shots

✦ and extreme sports

(Jerry Lodriguss)

(Dave Black)
Why is sports photography hard?

✦ sports move fast
✦ fields are big, arenas are dark
  • you don’t control the subject distance or the lighting
✦ you barely control the composition
  • long lenses compress the perspective
  • put yourself in the right place at the right time
  • know the game, know the players
✦ spray and pray
  • take 2000 pictures in a typical game
✦ post-process
  • big disk, fast computer, good workflow
  • mine is Lightroom + Photoshop
Lightroom

- browsing, ratings, color labels, syncing across computers, etc.
- common tools are well done: white balance, exposure, touchups
Ways of handling fast motion

✦ for most sports, “freezing” is the most interesting view
  • it’s also the easiest to capture reliably
Photographic variables

- shutter speed
- aperture
- ISO and noise
- focal length
- megapixels
- pixel size
- camera body
- metering/focusing modes
- frame rate
- burst size
- focus
- depth of field
- autofocusing
Shutter speed

Women’s volleyball
(Canon 1D III, 1/800 second)

- 1/1000 is min for typical framing and fast human motion
  - kicks, strokes, spikes, punches require 1/2000 or higher
Aperture

Women’s volleyball

(Canon 1D III, 1/800 second, ISO 3200, f/2.8)

- fighting for every photon, so wide open ("big glass")
- sacrifices depth of field even when you don’t want to
ISO

Women’s volleyball

(Canon 1D III, 1/800 second, ISO 3200)

- can sometimes control stadium strobes to add light
ISO and noise

Women’s gymnastics
(Canon 7D, 1/1000 sec, ISO 3200, f/1.8, 85mm)

✧ with mild denoising, ISO 3200 is fine on high-end cameras

denoised in Lightroom 2

original
ISO and noise

Women’s gymnastics

(Canon 7D, 1/1000 sec, ISO 3200, f/1.8, 85mm)

- with mild denoising, ISO 3200 is fine on high-end cameras
Focal length

- the right view often means shooting from far away
- long lenses are heavy, and they compress perspective

Canon 600mm/4.0
$8,000, 12 lbs

monopod
Physical affordances

- optical viewfinder
  - infinite resolution, dynamic range
- small LCD, because you seldom have time to look
- 2nd set of shutter controls when rolled for vertical shots
- large and heavy, especially the battery, circa 1500 shots
Other useability considerations

- analog “fighter pilot” controls, so requires lots of practice
- shoot RAW, M or Av, autofocus (AF) on, stabilization(IS) off
- hard to change lenses, so professionals carry multiple bodies
- few professionals use zooms - no time to fiddle, smaller aperture
- why no radio to upload the “decisive moment” to your publisher?
Megapixels and pixel size

Canon 1D Mark III
$3,800, 10 Mpix, 10 fps
7.2µ × 7.2µ pixels

- modest # of megapixels
  - but the pixels are big, which means less noise in low light
  - also permits fast readout, hence frame rate, and small files

- crop factor is 1.3× (APS-H)
  - not full-frame, which is too slow to read out
  - not 1.6× like APS-C format, which gathers less light

compare to 6.4µ on 21Mpix 5DII
Frame rate and burst size

Canon 1D Mark IV
$5,000, 16 Mpix, 10 fps
5.7μ × 5.7μ pixels
“standard” ISO to 12,800

✦ frame rate is (probably) limited by readout rate
  • 16 Mpix × 10fps × 16-bit pixels = 320 MB/s
  • mirror flip and shutter reset may also be limiters
  • shutter life is > 300,000 (only 150 games!)

✦ burst size is limited by writing to card
  • 121 JPEG or 28 RAW shots before buffer is full
Frame rate

Men’s water polo

(Canon 1D III, 1/2000 sec, ISO 200, f/4.5, 300mm)
Frame rate

Men’s water polo

(Canon 1D III, 1/2000 sec, ISO 200, f/4.5, 300mm)
Frame rate

Men’s water polo

(Canon 1D III, 1/2000 sec, ISO 200, f/4.5, 300mm)

✝ even 10fps is not fast enough for many sports

bursts are not identified on any current camera, so it’s hard to find them
Another example

Women’s soccer

(Canon 1D III, 1/1600 sec, ISO 200, f/4, 300mm)

+0.0s
Another example

Women’s soccer

(Canon 1D III, 1/1600 sec, ISO 200, f/4, 300mm)
Another example

Women’s soccer

(Canon 1D III, 1/1600 sec, ISO 200, f/4, 300mm)
Another example

Women’s soccer

(Canon 1D III, 1/1600 sec, ISO 200, f/4, 300mm)

✧ argh, missed again!
Another example

motion estimation / optical flow is unlikely to work
- to adjust shutter speed, perform denoising, view interpolation,...

Women’s soccer

(Canon 1D III, 1/1600 sec, ISO 200, f/4, 300mm)

might be able to adjust shutter speed in next frame based on motion blur in current frame

+0.4s
Nailing the shot: could the camera help?

- detect the ball, detect faces, trigger when they are close

- but can’t capture 60fps burst at full res on today’s cameras, so must be detectable from low-res viewfinder stream

- if cameras were faster, could capture a 60fps burst at full-res and save the decisive shot

- or let the photographer choose which frames to save (like Casio EX-F1), but when do they have time for this?

Moore’s Law will help

(Hector Garcia-Molina)
Focus

Women’s lacrosse

(1D III, 300mm, 1/4000 sec, ISO 800, f/3.2)

✓ critical focus
Depth of field

\[ D_{TOT} \approx \frac{2NCU^2}{f^2} \]

- \( N = f/4 \)
- \( C = 7.2\mu \)
- \( U = 15m \ (50') \)
- \( f = 300mm \) (equiv to 384mm)
- \( D_{TOT} = 144mm \ (6'') \)

- DoF is demanding at low F-numbers and long focal lengths!
- 1 pixel on this video projector
  \[ C = 7.2\mu \times \frac{3984}{1024} \text{ pixels} \]
  \[ D_{EFF} = 560mm \ (22'') \]
Shallow depth of field is useful

Women’s lacrosse

(1D III, 400mm, 1/4000 sec, ISO 400, f/4)
Depth of field can be too shallow

- ability to extend depth of field would be useful
  - different problem from fixing misfocus
  - fighting for photons, so can’t stop down the aperture

Big Game 2009

(7D, 300mm, 1/1250 sec, ISO 1600, f/2.8)
Autofocusing

Women’s lacrosse

(1D III, 400mm, 1/5000 sec, ISO 400, f/4)
Autofocusing

Women’s lacrosse

(1D III, 400mm, 1/5000 sec, ISO 400, f/4)

✦ single centered AF point is most reliable
• otherwise it often focuses on peripheral players or objects
Subjects aren’t always centered

✦ use manual AF button, before or during action
  • requires a lot of practice
Auto-misfocusing

Women’s lacrosse

(1D III, 400mm, 1/4000 sec, ISO 400, f/4)
Auto-misfocusing

Women’s lacrosse

(1D III, 400mm, 1/4000 sec, ISO 400, f/4)

- solve by prohibiting focusing on the grass?
  - trainable before the game, to allow unusual fields
  - use color & texture?

- or focus on moving objects?
  - as detected by motion blur
  - must overlook/compensate for panning the camera
Auto-misfocusing

Women’s soccer

(1D III, 400mm, 1/2000 sec, ISO 200, f/4)
Auto-misfocusing

Women’s soccer

(1D III, 400mm, 1/3200 sec, ISO 200, f/4)

- fix focus in blurry shot using information from sharp shot later in the same burst?
Personal photo enhancement using example images [Joshi 2011]

- how much better could this be if the sharp priors were taken a few seconds before the blurry shot?

original blurry image

our automatically deblurred output
Auto-misfocusing

Women’s soccer

(1D III, 400mm,
1/3200 sec, ISO 200, f/4)

- fix focus in blurry shot using information from sharp shot later in the same burst?
- also applicable to casual photography - use imagery captured while aiming and focusing to fix noise, blur,...
Auto-misfocusing

Women’s soccer

(1D III, 400mm, 1/2000 sec, ISO 200, f/4)
Auto-misfocusing

Women’s soccer
(1D III, 400mm, 1/3200 sec, ISO 200, f/4)

✦ need “soccer ball focus”
  • plug-in for sports
  • trainable before the game, to allow unusual balls
  • specialized algorithm to recognize any rotation
  • could also use to set white balance and exposure
“Pre-game warmup” for cameras

- train on ball
- train on each player
- adjust focus and exposure for best shot
- adjust depth of field to span player and ball

Courtney Verloo
This is harder than it sounds

Courtney Verloo

player carries wireless chip?
The many faces of Kelley O’Hara

✦ top U.S. collegiate soccer player 3 years in a row
Auto-misfocusing

Women’s lacrosse

(1D III, 400mm, 1/4000 sec, ISO 400, f/4)
Auto-misfocusing

Women’s lacrosse

(1D III, 400mm, 1/4000 sec, ISO 400, f/4)

- solve by prohibiting focusing beyond a certain distance?
  - tricky since camera often pans and field is rectangular
Plenoptic camera + post-focusing

Big Game 2009

(Canon 50D with microlens array, 300mm, 1/500 sec, ISO 1600, f/4)
How much refocusing do we need?

Big Game 2009

(Canon 50D with microlens array, 300mm, 1/500 sec, ISO 1600, f/4)

\[ D_{TOT} \approx \frac{2NCU^2}{f^2} \]

- \( N = f/4 \)
- \( C = 4.7 \mu \)
- \( U = 25m \ (82') \)
- \( f = 300mm \) (equiv to 480mm)
- \( D_{TOT} = 261mm \ (10'') \)

- 1 pixel on this video projector
  \( C = 4.7\mu \times \frac{4752}{1024} \) pixels
  \( D_{EFF} = 1.2m \ (4') \)
How much refocusing do we need?

- prototype camera was approximately $400 \times 300$ microlenses, with $\sim 12 \times 12$ pixels behind each microlens = 18 megarays
- depth of field (on video projector) = 6'
- refocusability with this recipe = $6' \times 12 = 72'$
- length of a football line of scrimmage = $\sim 20'$ (not including the wide receivers)
- alternative recipe: $1200 \times 900$ microlenses, with $4 \times 4$ pixels behind each microlens
- refocusability with alternative recipe = $6' \times 4 = 24'$
Shots that could have been saved

✧ almost well focused
Shots needing a bit more DoF

✦ refocus to create focal stack, apply all-focus algorithm
  • or another EDoF technique: coded aperture, lattice focal, etc.
Shots that could use a tilted focal plane

✦ easily done with light field camera
✦ curved focal surfaces also possible

(Hector Garcia-Molina)
Meaningless backgrounds

(Hector Garcia-Molina)

- no solution except to look for a different vantage point
Cluttered backgrounds

Women’s gymnastics

(Canon 7D, 1/1000 sec, ISO 3200, f/1.8, 85mm)

✦ common problem in most indoor and stadium sports
Fixing cluttered backgrounds

Women’s soccer

(1D III, 400mm, 1/2500 sec, ISO 200, f/4)
Fixing cluttered backgrounds

Women’s soccer

(1D III, 400mm, 1/2500 sec, ISO 200, f/4)

cropped
original

• this took a long time to do
  • darkened and desaturated using Lightroom 2’s “auto-masked” brush
  • need focus-based region selector for editing
Conclusions

- some aspects of sports photography are intrinsically hard
- some might yield to comp photo / vision algorithms
- faster bursts (or video) would help
- camera as light field probe - frameless photography?
- new ways of depicting sports action?
Parting thoughts:
good sports photographers make it look easy

(Hector Garcia-Molina)
Another parting thought: sports can be rough

(Hector Garcia-Molina)
Parting thoughts:
swing the camera around once in a while

(Marc Levoy)