Real-Time Camera Tracking in the "1st & Ten" System

Louis Gentry and Rand Pendleton

What is “1st & Ten”?

1st & Ten, Line of Scrimmage, and Down and Distance

1st & Ten

- “1st & Ten” is a real-time visual effects system designed to insert virtual graphics in live football broadcasts with proper in-scene perspective.
- Invented by Sportvision in 1998 and debuted on ESPN Sunday Night Football that same year.
- Relies on hardware sensors for accuracy.

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1st and Ten Demo

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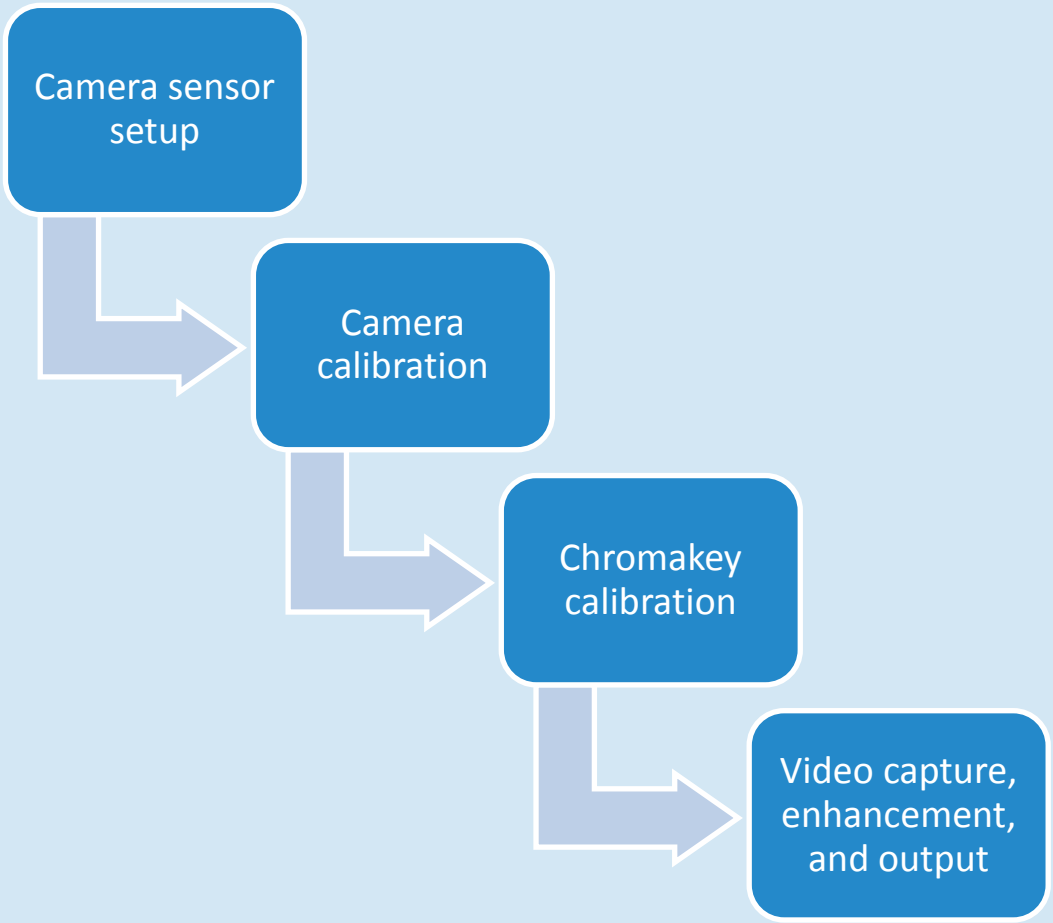
Sensor System Workflow



Process for enhancing life video from a locked-down camera.

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Sensor System Pros and Cons

Pictured: Assembled, instrumented camera

Pictured: Sportvision instrumentation box

- Pros
  - Once calibrated, it “just works”
  - Works even on snow games
  - Minimal tuning required
  - Not affected by motion blur
- Cons
  - Requires fixed camera position
  - No reliable hardware-based image stabilization
  - Cost of custom electronics
  - Must be onsite with the TV production

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“1st & Ten” on Movable Cameras?

Pictured: skycam

Pictured: Yellow Line as drawn by the skycam

- Most movable broadcast cameras have prohibitive constraints:
  - Weight
  - Data connectivity
- Use an optical solution where sensors aren’t practical
- In 2004, Sportvision pioneered an optical tracking system for enabling “1st & Ten” on football replays.

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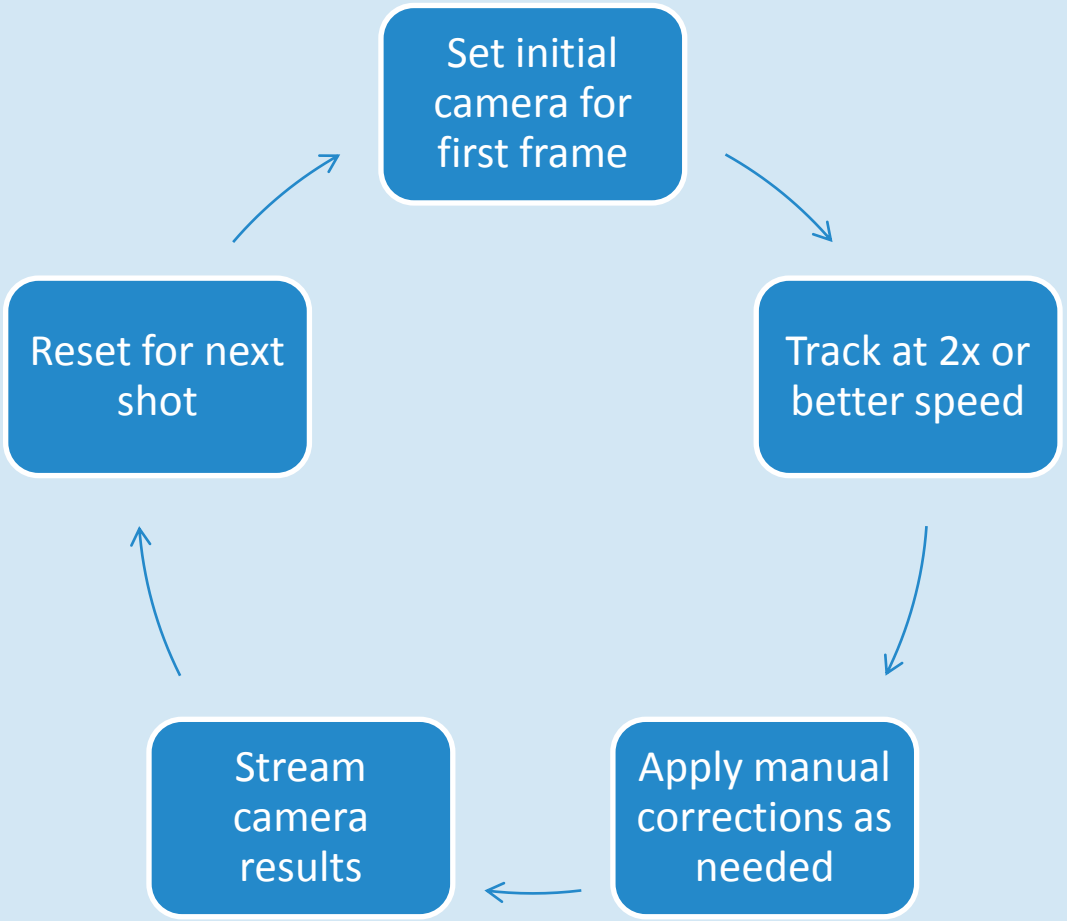
Legacy Optical System

- Requires no instrumentation/sensors
- Image processing on CPU
- Designed for replays
- Debuted on ESPN Sunday Night Football

Optical System Workflow



Limitations of Legacy Optical System

- Limited CPU computing
- Limited feature search regions
- Greater than desired number of noisy measurements
- Limited to analyzing every other frame
- Often requires manual correction of tracks

How Does Today's GPU Compute Power Help?

- Reduced compute cost
- More compute power
- Better scalability

Legacy Implementation

- Limited to template matching
- Averaged 115 point and 60 line measurements per solve
- Required interpolation of camera solution

New CUDA-Based Optical System

Intel CPU

NVIDIA QUADRO graphics card

AJA video capture card

Supermicro motherboard

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Live Optical Tracking Test

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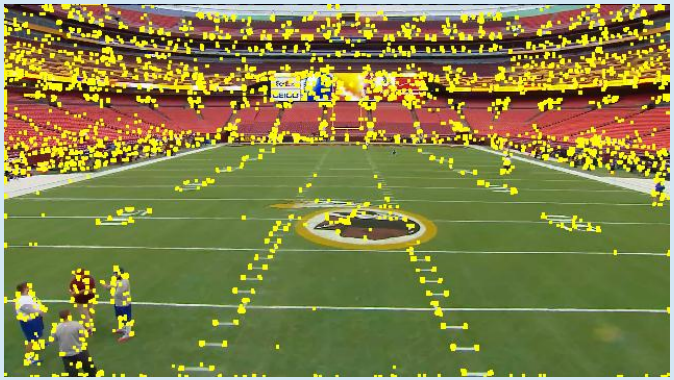
Improvements Using the GPU



- More sophisticated feature detection
  - Strong features to track
  - Less matching ambiguity
  - Reduced drift and noise in calibrations
- Increased number of high-quality measurements

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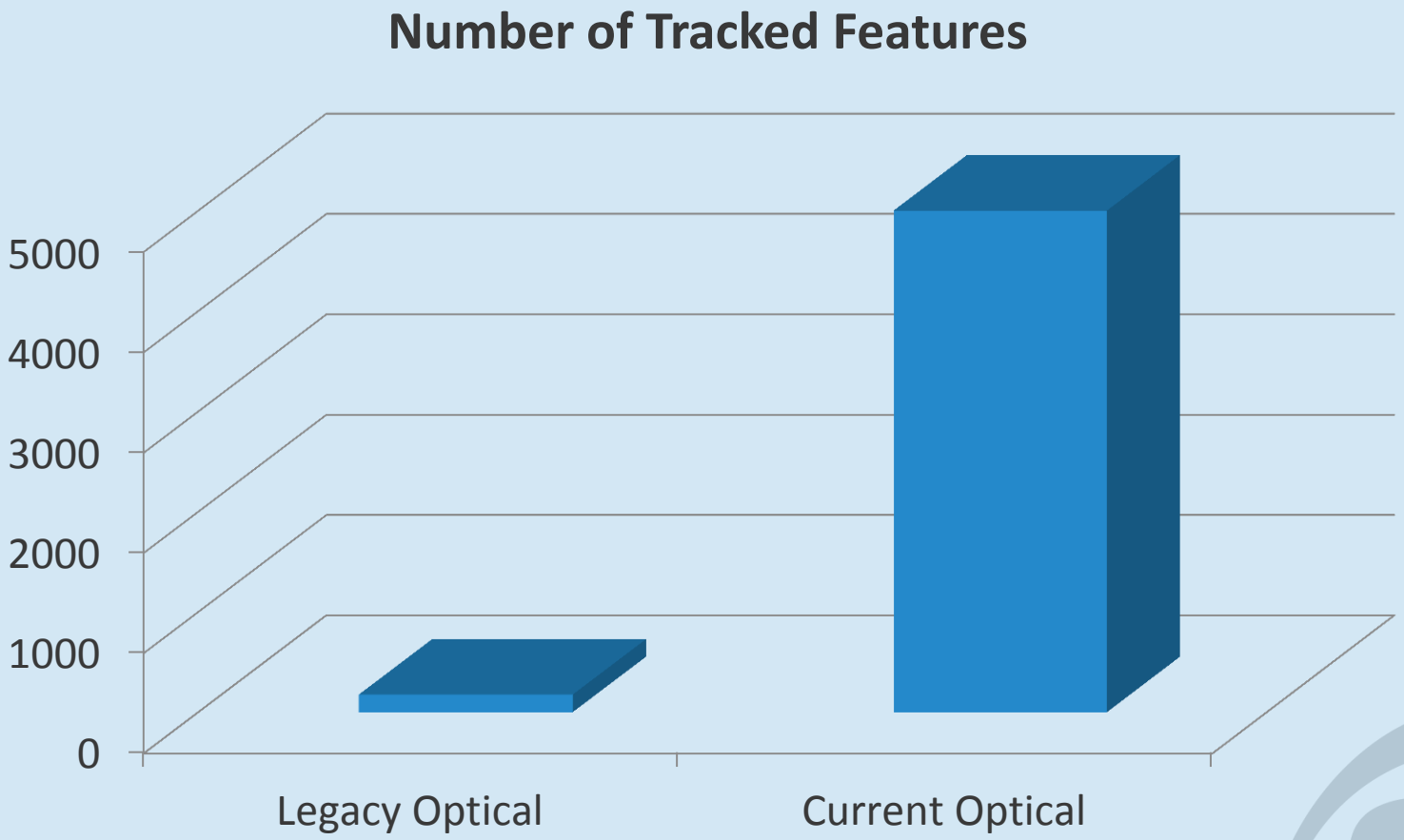
Improved Detection

- Disambiguate features
  - Tried industry standard techniques (Harris, SIFT, FAST, etc.)
  - Utilized a combination of industry and proprietary techniques
- More robust features
  - Better differentiation between hash mark corners in close proximity
  - Reduced false positives (particularly along yard lines)

Metrics Comparison



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Lessons Learned

- Primarily memory bound
  - Had to use creative methods to hide latency
- Adhering to known CUDA optimization guidelines is a must
  - Coalesced memory access
  - Minimizing shared memory bank conflicts
  - Efficient use of shared memory
  - Avoid divergent warps
  - Use pinned memory to reduce CPU/GPU transfer costs

Final Thoughts

- Always more to do
  - Optical solutions are often domain/context specific
  - Often need multiple solutions to cover different camera angles

- Never enough compute
  - Need sophisticated algorithms
  - Real-time requirement adds hard constraints

louisgentry@sportvision.com
randpendleton@sportvision.com

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