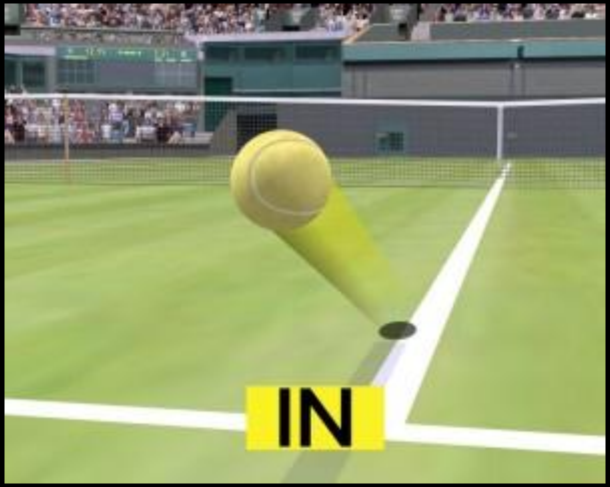
Computer Vision



SPORTS

Presented by Alex Golts

Talk Outline

- General overview
- Applications & examples
- Main challenges
- "FoxTrax" – Hockey puck tracking system

  R. Cavallaro. The FoxTrax hockey puck tracking system. IEEE Computer Graphics and applications, 17(2):6–12, 1997.

- Players tracking system

  Computer vision system for tracking players in sports games, J Pers, S Kovacic, ISPA'00

- Summary

General Overview

Computer vision is used in sports for several kinds of benefits:

- Improving broadcast / viewer experience
- Improving the training process of professional athletes
- Automatic sports analysis and interpretation
- Helping / improving referee decisions
- Commercial benefit

Applications & Examples

Improving broadcast / viewer experience

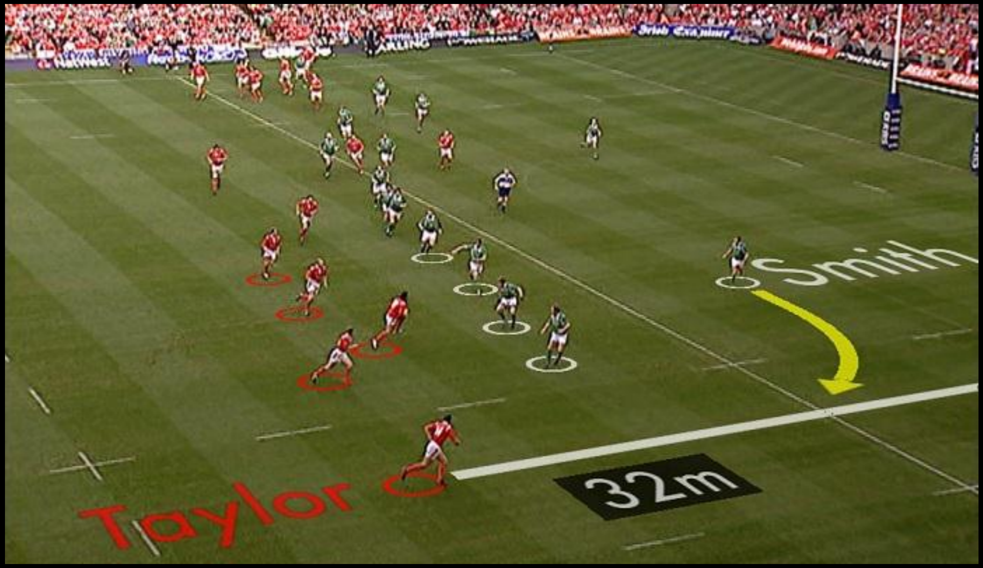
- “Fox Trax” – Hockey puck tracking system

System will be described later on …

Applications & Examples

Improving broadcast / viewer experience

- Drawing virtual marks across a football field



Applications & Examples

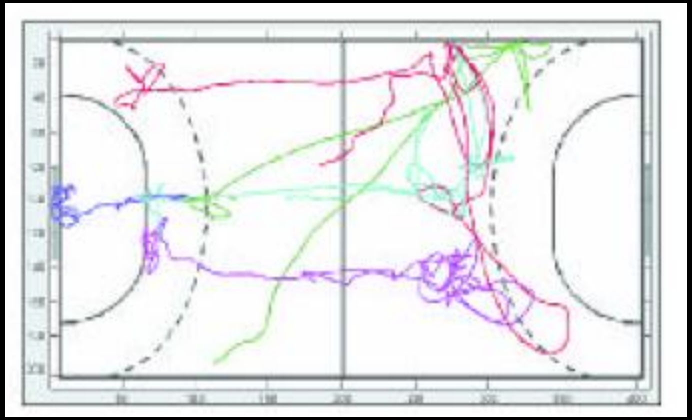
Improving the training process of professional athletes

- Estimation of center-of-mass by manually fitting a skeleton model

Applications & Examples

Automatic sports analysis and interpretation

- Tracking of players in a sports game

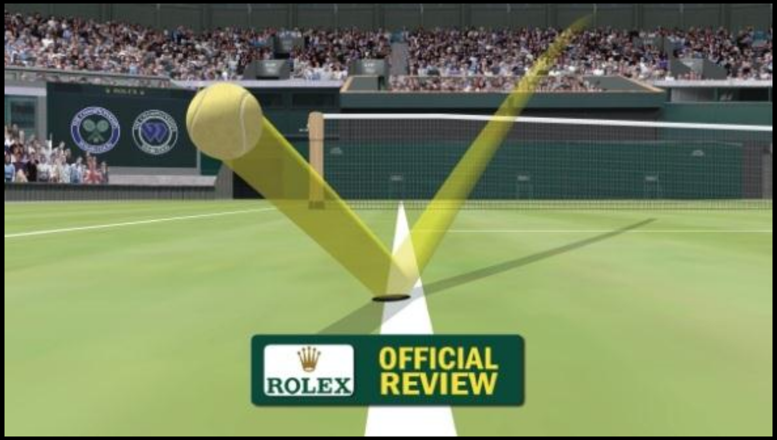


System will be described later on …

Applications & Examples

Helping / improving referee decisions

- “Hawk Eye” tennis system



Applications & Examples

Commercial benefit

- Real time billboard substitution in video streams

Main challenges

- Changing / unknown environment – lighting, background, clothing, scale, moving camera …
- Real-time live performance
- Provide innovation and value-for-money
- Robustness and accuracy
- Convince “conservative” regulators and critics…

FoxTrax

Problem

Hockey puck is difficult to follow for viewers

FoxTrax

In 1996, Fox Sports wanted to highlight the puck for the viewers without players feeling any difference.

- Highlight should be made even when the puck is hidden behind objects.
- Puck speed can reach over 100mph, and sometimes get blurred / disappear between TV scan lines.

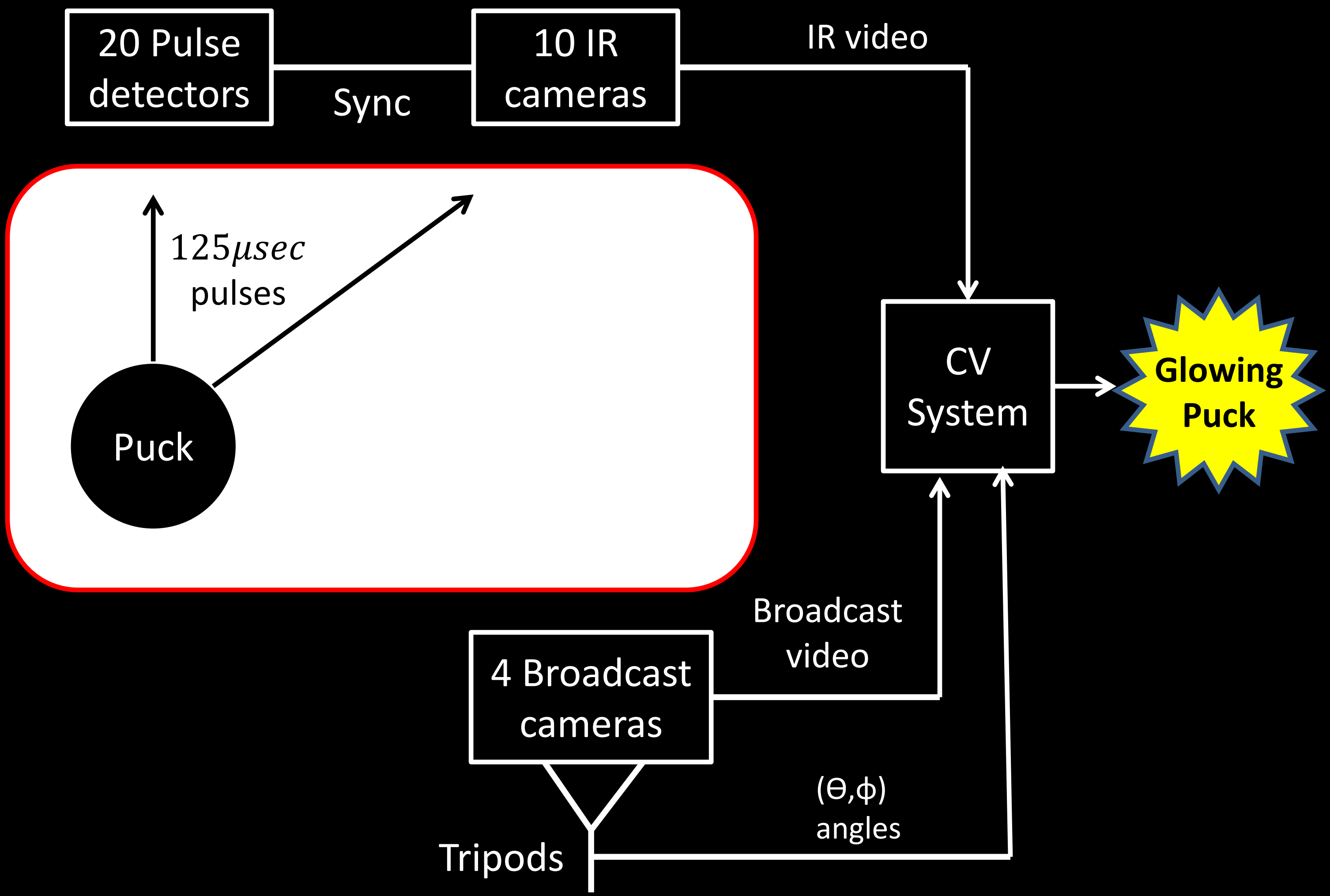
⇩

Simply processing the raw broadcast video was not enough

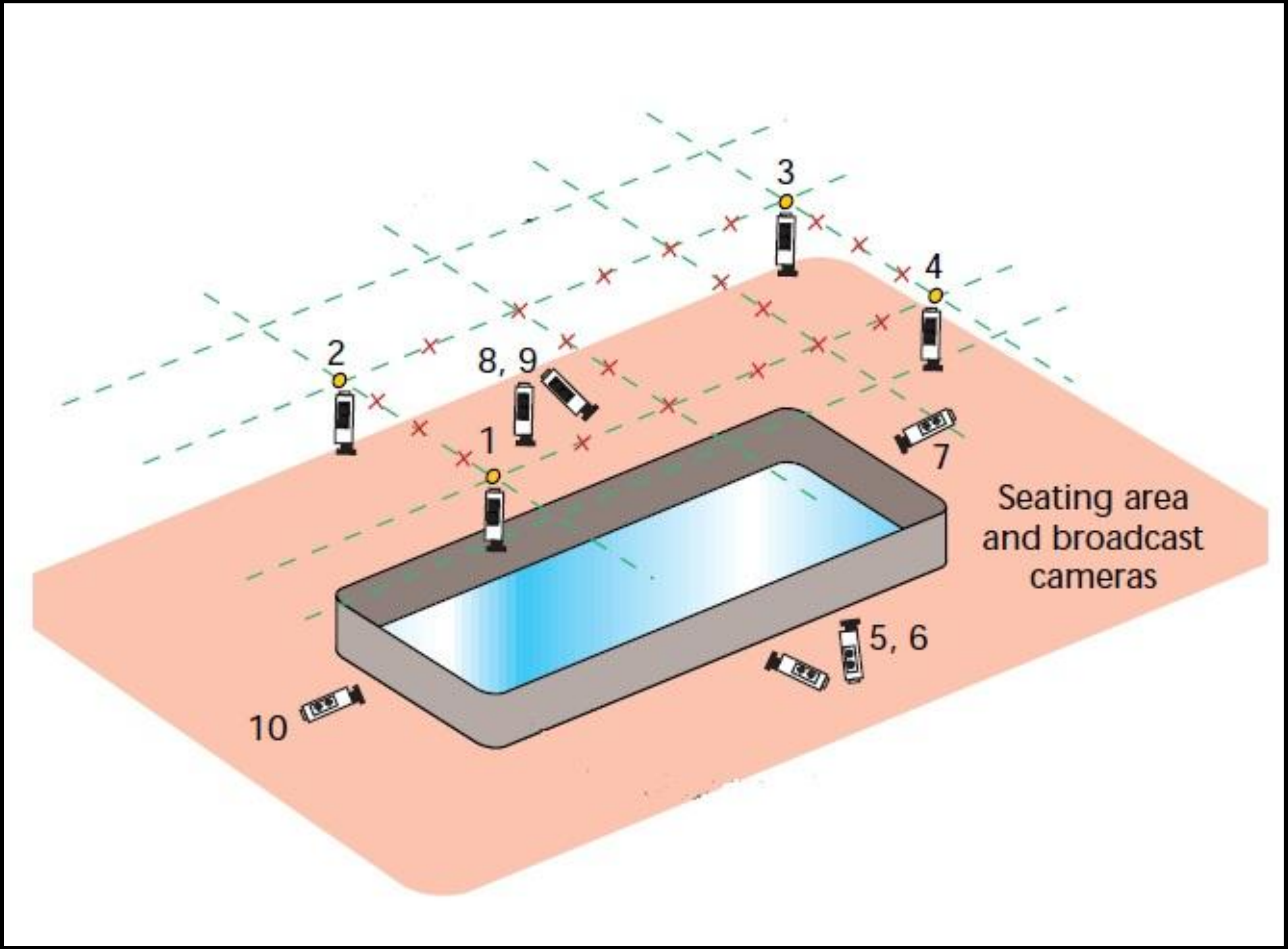
FoxTrax

Solution: IR emitting puck

System Architecture



System Architecture



Computer Vision System

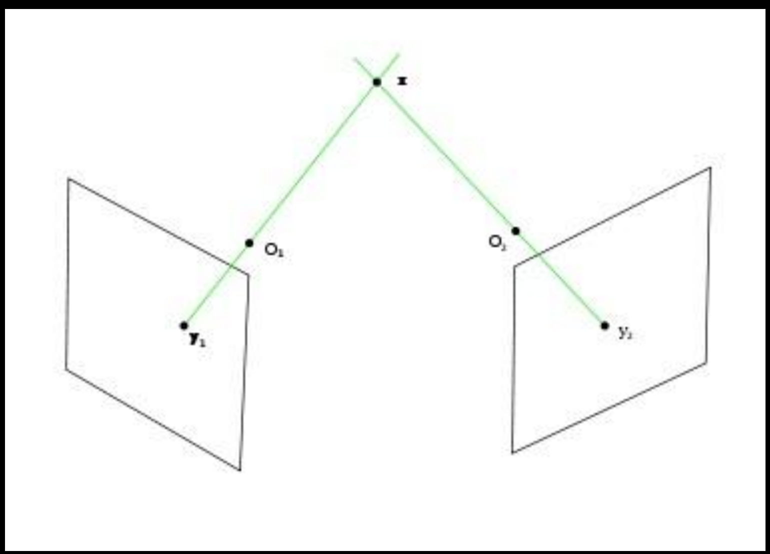
Calibration

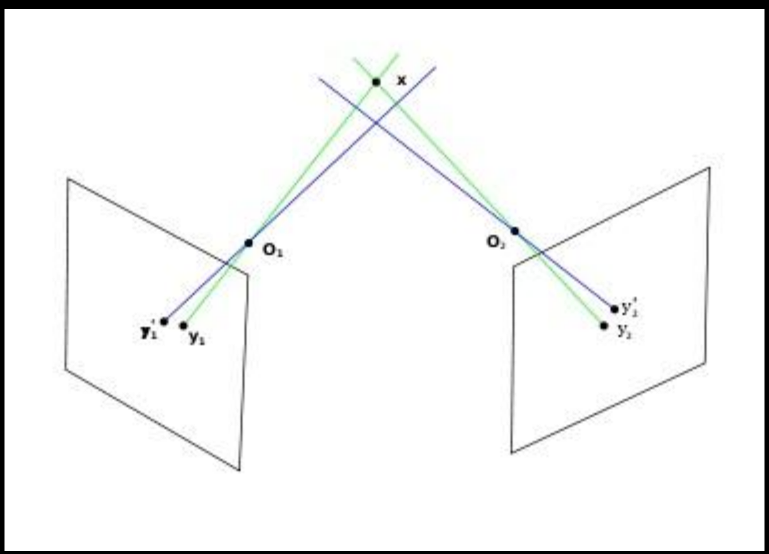
- Measuring rink dimensions – Origin is defined at the central face-off circle. Rink borders are measured using laser range-finder.
- Camera position calibration – For both IR and broadcast cameras. Puck is placed at points of known location at the rink, and viewed from all cameras. Software computes camera positions.
- Distortion correction – For both IR and broadcast cameras. Compute the distortion maps in the lab.

Computer Vision System

Triangulation

At least 2 IR images with line-of-sight to the puck





Puck (X,Y,Z) coordinates

Computer Vision System

Projection

- Tripod (Θ,ϕ) angles
- Broadcast camera
  zoom state

→ $\begin{pmatrix} Camera \\ Matrix \end{pmatrix}$ ←

Puck (X, Y, Z)
coordinates

↓

Puck (x,y) camera
coordinates

↓

Add Glow

Computer Vision System

Delay and past data usage

- The algorithm works at 30[Hz] with a 5 frames delay.
- Additional 5 frames delay was added – allows to deal with the puck being “lost” for 5 frames – by interpolation.
- Special effects added depending on puck speed

FoxTrax

Result – 1996 NHL All-Star game

FoxTrax – The end

At first, the new technology was successful, but many hockey fans (especially Canadians) disliked it.
It lasted until 1998's all star game.

FoxTrax – Summary

- The solution worked as expected. People were happy at first
- “Die hard” hockey fans are hard to please.
- Solution (For today): It’s a free country, Just make it optional!
- Or make the effect less “video game” like.
- Solution seems too expensive, and “heavy” (remember it’s 1996). Seems like today it might be possible to achieve with just a CV algorithm (?)

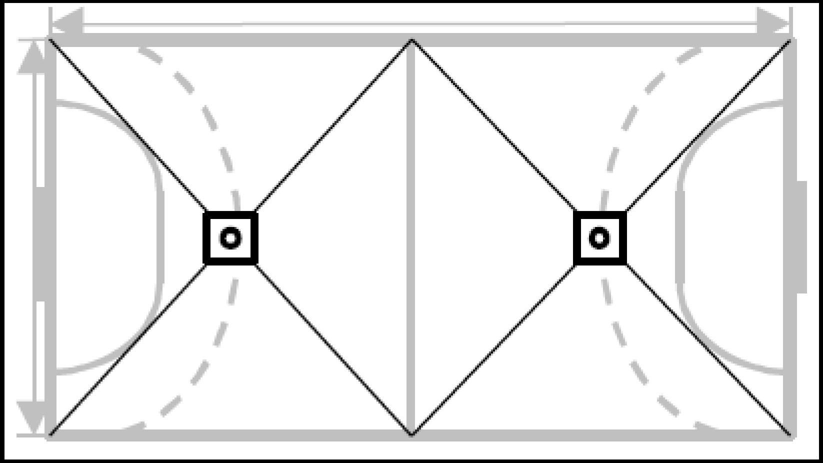
Computer Vision System for Tracking Players in Sports Games

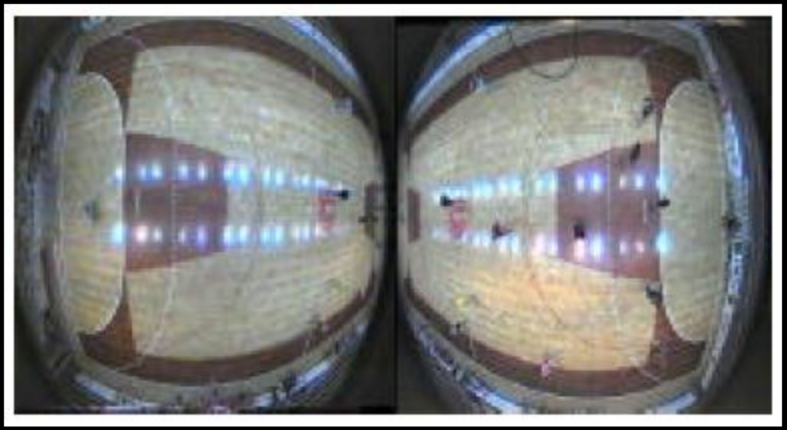
Problem

Indoor sports game → **Computer Vision System** → Player spatio-temporal trajectories

Players Tracking System

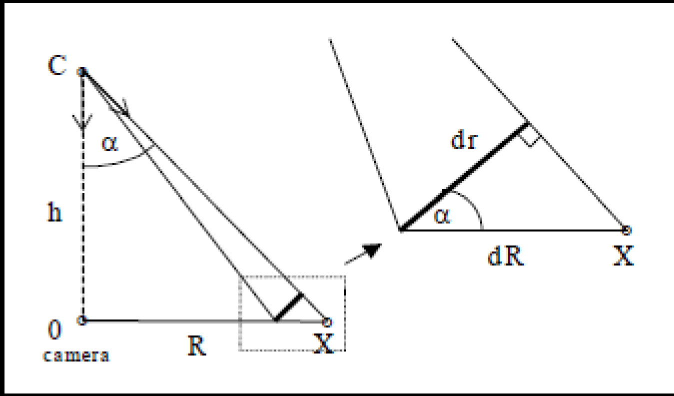
Cameras





Players Tracking System

Distortion Calibration



$$\int_0^{r_l} dr = \int_0^{R_l} \cos\left(\arctan\left(\frac{R}{h}\right)\right) dR \Rightarrow R_l = \frac{h}{2} \cdot \frac{e^{-\frac{2r_l}{h}} - 1}{e^{-\frac{r_l}{h}}}$$

Players Tracking System

Player tracking – motion detection

- Subtract each frame, C from reference frame, R (empty court):

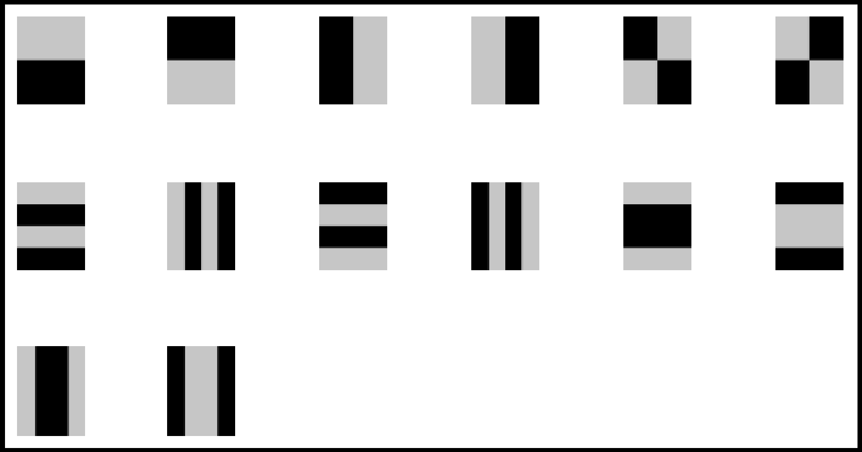
$$D = |R_C - R_R| + |G_C - G_R| + |B_C - B_R|$$

- Apply noise filtering and threshold
- Results in many false detections due to shadows, noise etc'… Human intervention often required

Players Tracking System

Player tracking – template tracking

- 14 2D templates (16x16 pixels) - K_j $(j = 1, \ldots, 14)$:



Players Tracking System

Player tracking – template tracking

- For each pixel's R,G and B components, compute the correlation:

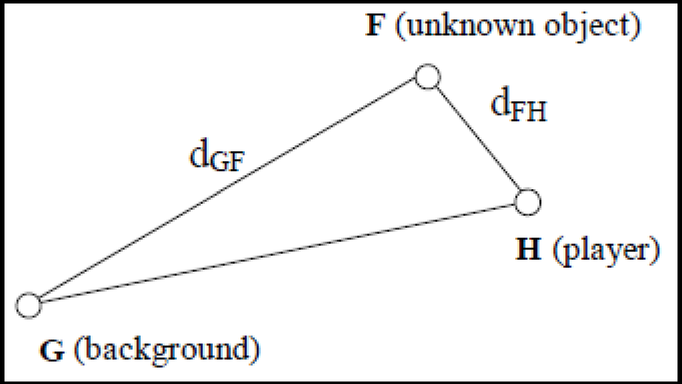
$F_j(x, y) = K_j \otimes I(x, y)$ ➡ 14x3 = 42 coefficients per pixel

- Similarly, $G_j(x, y)$ are calculated from the reference frame, R.
- $H_j(x, y)$ are calculated by averaging the last n coefficients $F_j(x, y)$. Represents "average" player appearance.

Players Tracking System

Player tracking – template tracking

- A distance measure is calculated to compare F_j, H_j and G_j in each pixel



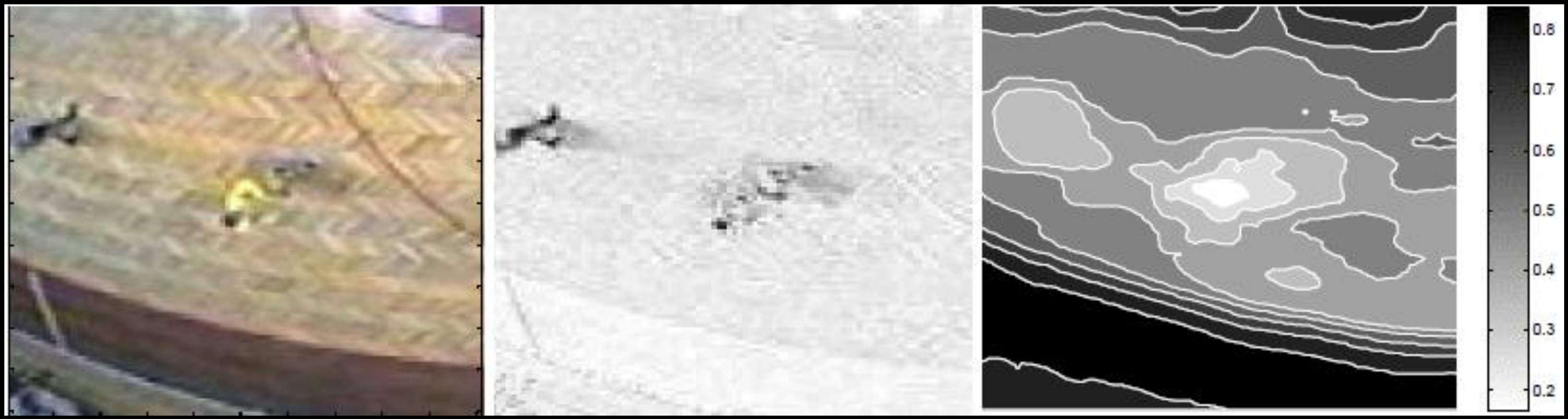
$$s = \frac{d_{FH}}{d_{FH} + d_{GF}}$$

$$d_{GF} = \sqrt{\sum_{j=1}^{42} (F_j - G_j)^2}$$

$$d_{FH} = \sqrt{\sum_{j=1}^{42} (H_j - F_j)^2}$$

Players Tracking System

Player tracking – template tracking



Real player image Difference image Similarity measure

Players Tracking System

Player tracking – color tracking

- Based on prior knowledge of the player's uniform color – (C_R, C_G, C_B).
- The algorithm searches for the pixel with the most similar color to the player's color in a limited area around the last player position.
- Similarity measure:

$$S(x,y) = \sqrt{(I_R(x,y) - C_R)^2 + (I_R(x,y) - C_R)^2 + (I_R(x,y) - C_R)^2}$$

Players Tracking System

Results

- 3 methods were tested: A – motion detection, B – color tracking, C – color + template tracking.
- Tested on 30 seconds of handball match, and 50 seconds of a "test sequence" where the players stood still (measured distances correspond to noise).

Method	Interventions	Noise	Time
A	45	80 meters	0.424 sec/frame
B	12	249 meters	0.175 sec/frame
C	14	55 meters	0.229 sec/frame

Players Tracking System

Summary

- Semi-automatic system that outputs players trajectories.
  Human interventions are required for error-free performance.
- 3 algorithmic approaches were tested.
- The system can serve as base for a complete sports analysis system.
- Semi-real-time. 5[Hz] can be achieved at best. However, today much faster computers are available.
- Resolution was low. Each player takes only 10-15 pixels in the image.
- These relatively poor results perhaps explain why “Fox Sports” went for a much more sophisticated approach.

Computer Vision in Sports

Summary

- CV is used in sports used for: broadcast, training, automatic analysis, decision making and commerce.

- In broadcast enhancement and auto-analysis, object tracking is often needed. Hockey puck tracking, and players tracking systems were discussed.

- Most of CV technology in sports is implemented in industrial products, and not properly documented (besides patents). Academic works are not easy to come by, and there's room for development.

- Besides the technological challenges, progress depends on acceptance of change in a conservative environment, strict regulations, and the real need for improvement.

Thank You