

计算摄像实验室 @ 南京大学

Computational Imaging Lab @ Nanjing University

<http://cite.nju.edu.cn>

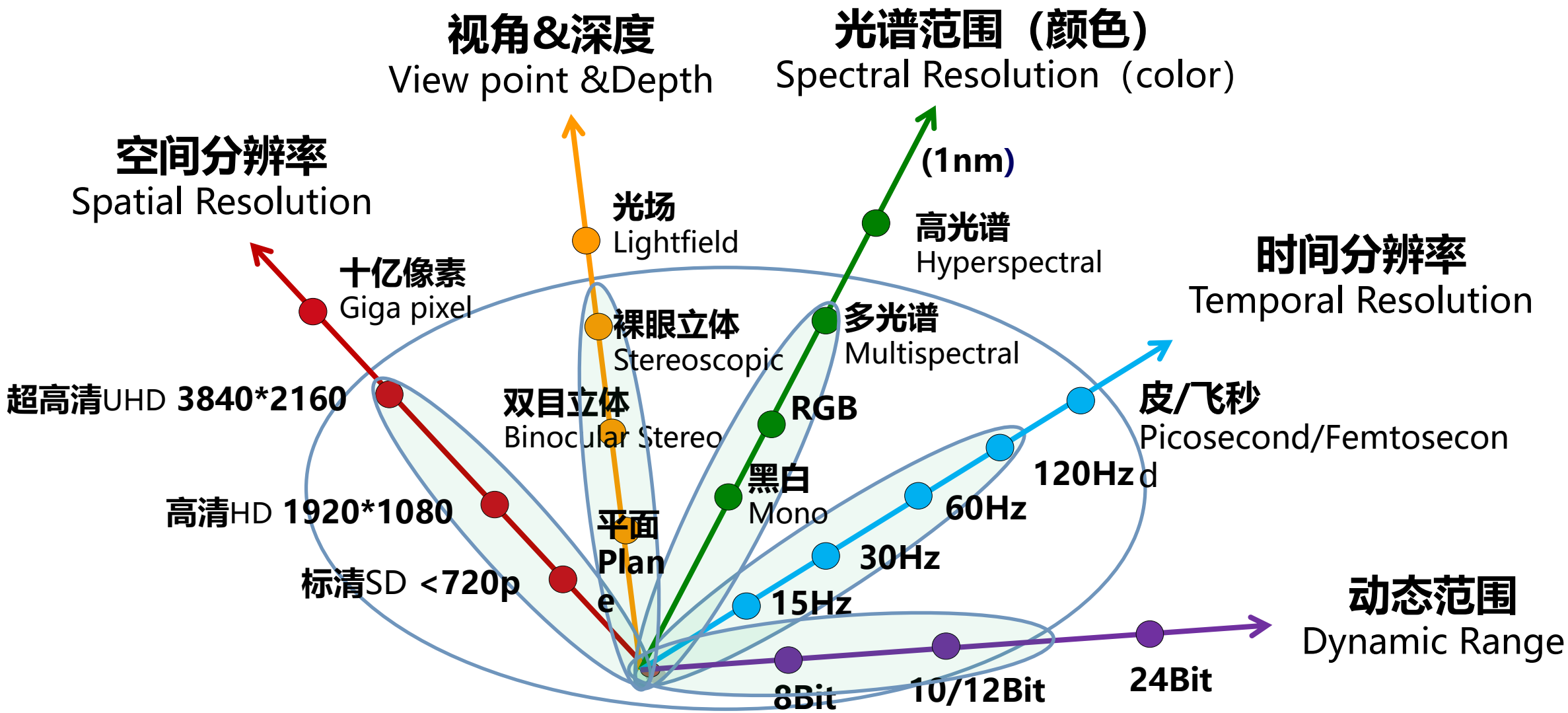
Computational Imaging Technology & Engineering

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Xun Cao

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相机发展趋势 Towards Better Camera



重点研究：三类计算摄像系统

Focus On **Three Types** of Computational Imaging System

□ 深度维度 Towards Depth Dimension

- 多相机系统 Many-Camera System

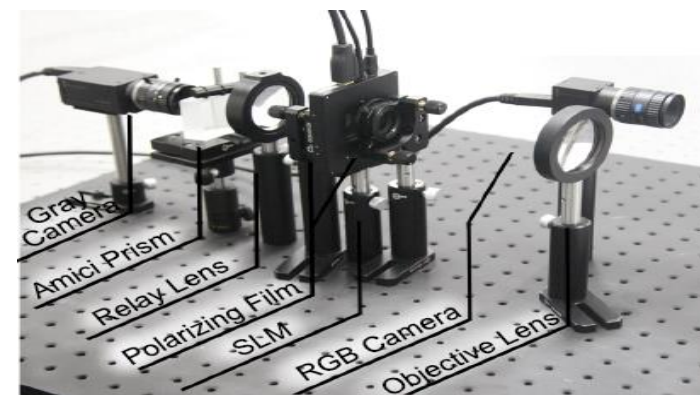
□ 颜色维度 Towards Color Dimension

- 高分辨率光谱视频相机: **PMIS**

High resolution spectral video camera: **PMIS**

□ 空间维度 Towards Spatial Dimension

- 十亿像素成像 Gigapixel imaging



三维采集技术比较 Comparisons of 3D acquisition methods

光场矩阵 Camera array : 3D+

- 单次曝光同步拍摄 - “快”

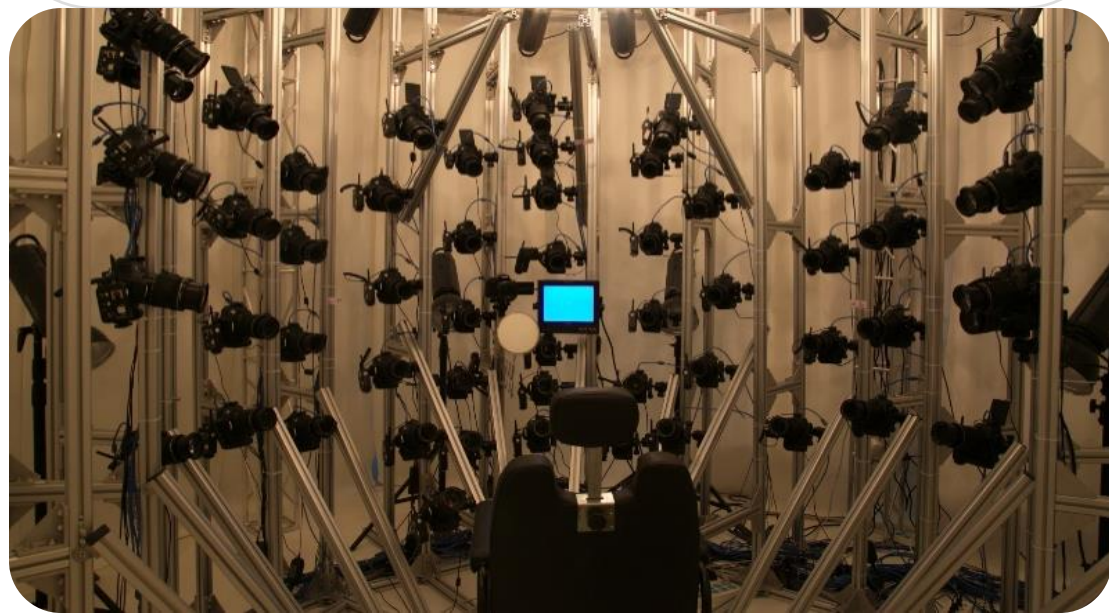
Synchronized Capture with single exposure

- 3D模型 + 纹理 同时捕获 - “真”

Capture 3D model + Texture simultaneously

- 高精度 (亚毫米级) - “准”

High Accuracy (ubmillimeter)



VS

结构光/激光 3D扫描仪

- 扫描时间长 (静止物体, 不能瞬时拍摄)

Time consuming

- 无法拍摄透明/半透明物体

Unable to capture transparent/translucence objects

- 能获得几何模型, 无法采集纹理和颜色

Unable to capture texture and color

- 商用级精度无法达到亚毫米级

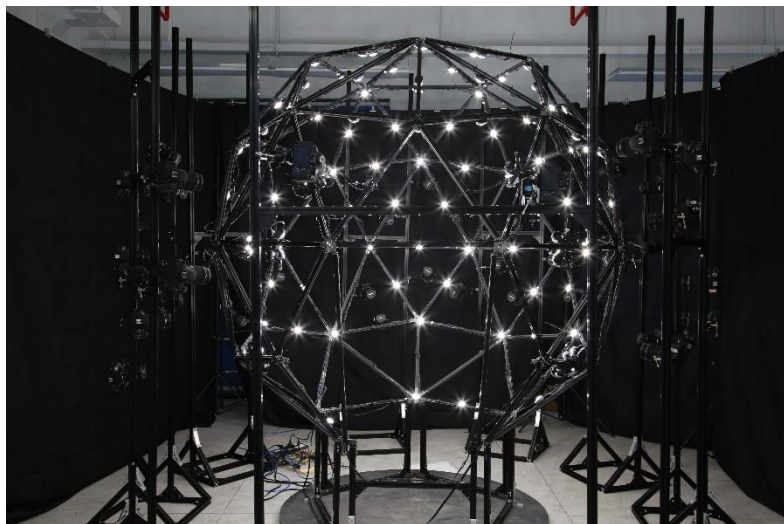
Lower accuracy



多相机系统 Many-Camera System

致敬：金出 教授
hats off: Prof. T. Kanade

-5-



面部/身体 捕捉系统 – 144相机
Facial / Body Capture – 144 Cams



国内首部真人CG电影
《爵迹》
Movie Poster for
<L.O.R.D>



国内首部全球公映CG
电影《妈妈咪鸭》
Movie Poster for
<Duck Duck Goose>

应用：文物保护与重建 Application: Cultural Relics Protection



其他重要应用领域 Other applications:

- 1. 工业4.0 Industry 4.0
- 2. 虚拟电商展示 E-commerce demo
- 3. VR/AR

重点研究：三类计算摄像系统

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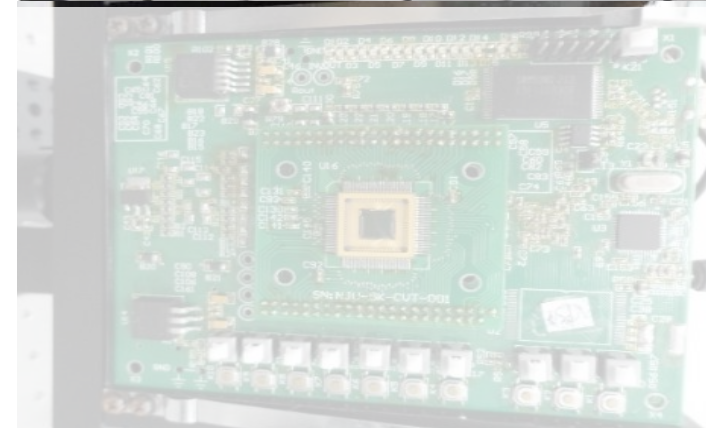
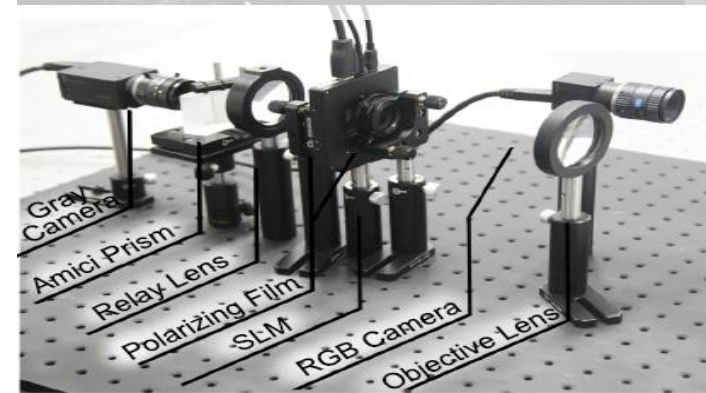
□ 颜色维度 Towards Color Dimension

- 高分辨率光谱视频相机: **PMIS**

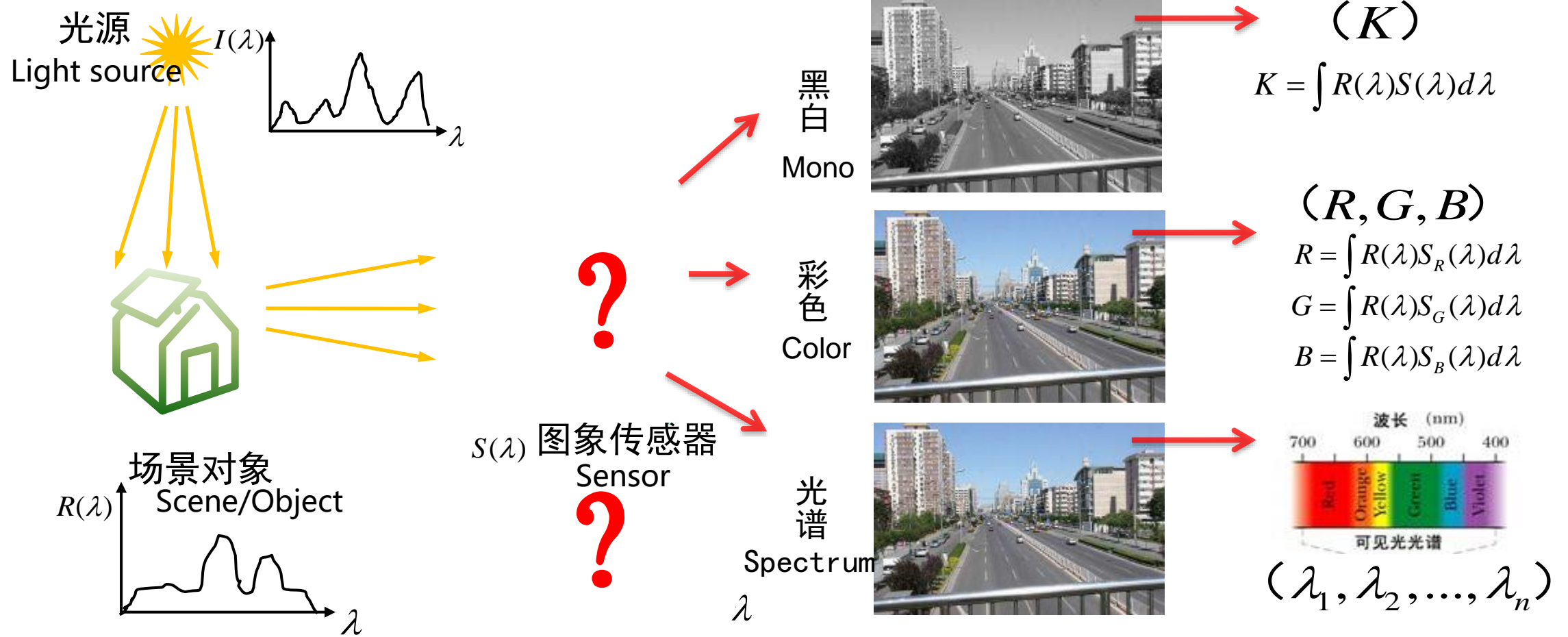
High resolution spectral video camera: **PMIS**

□ 空间维度 Towards Spatial Dimension

- 十亿像素成像 Gigapixel imaging system

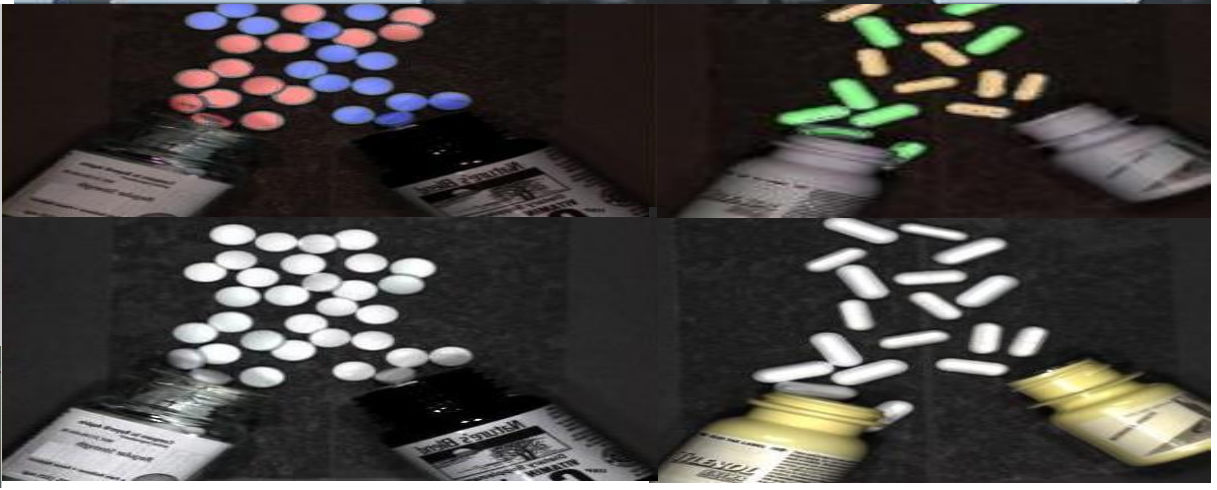
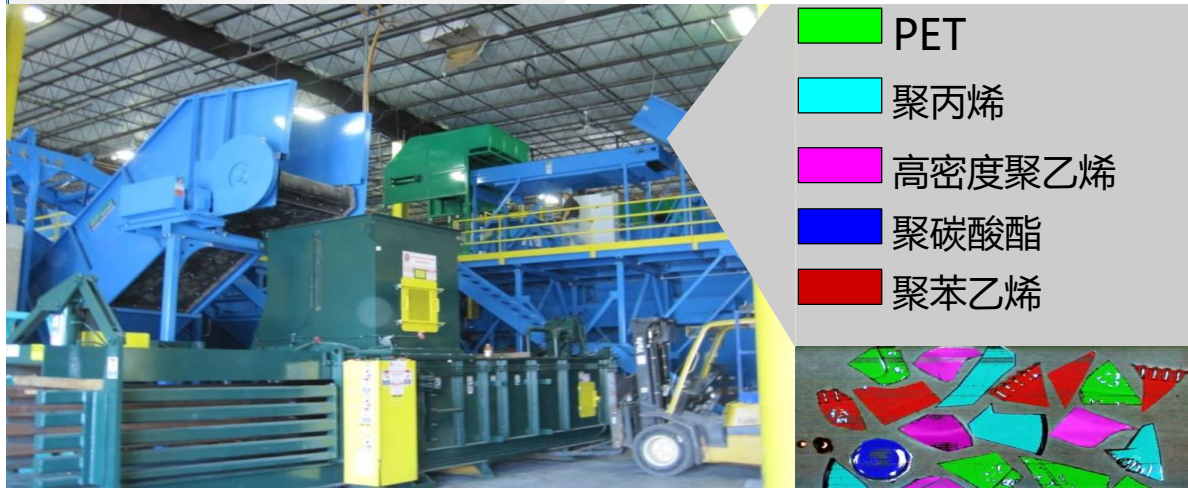
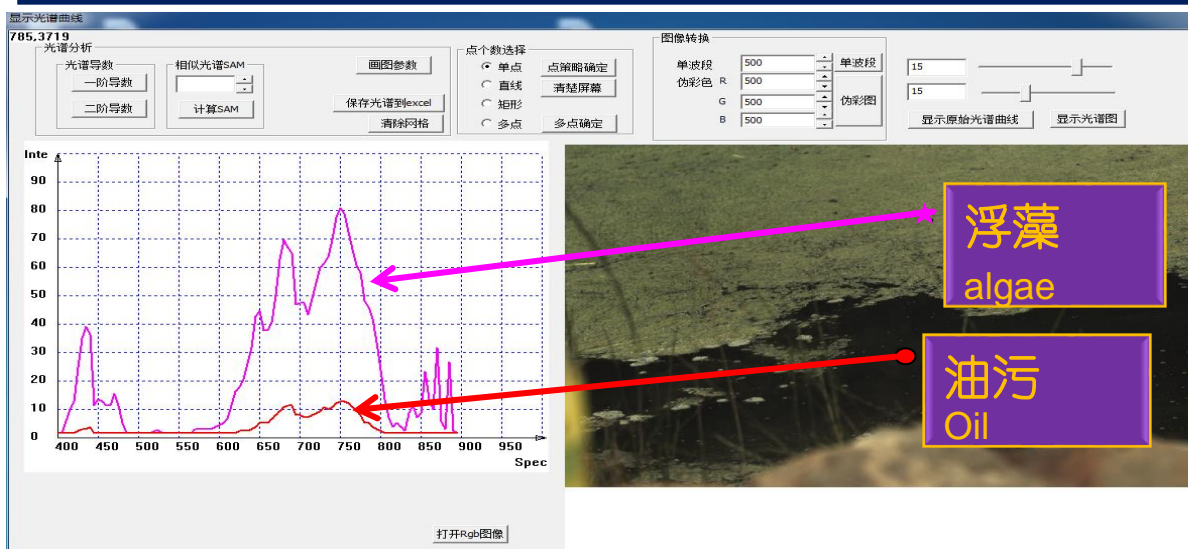


研究背景 Motivation



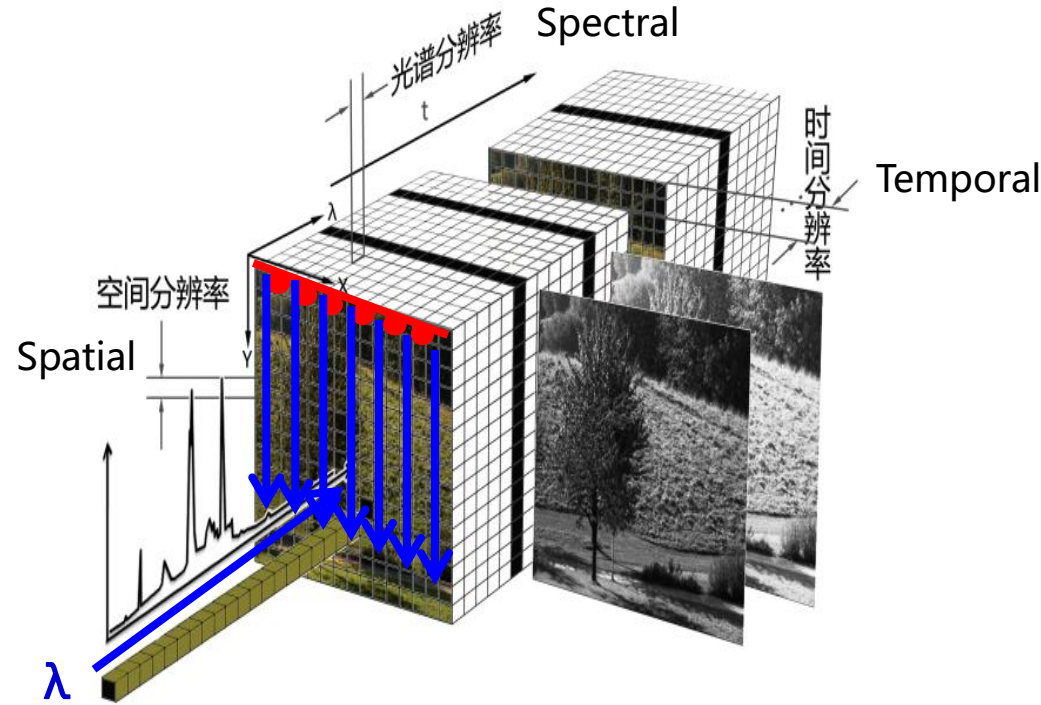
光谱探测物质成分的光学辐射，揭示物质本质属性，是自然物质的光学基因 (DNA)
 Spectrum is the DNA of light, which characterize the material of different objects

研究背景 Motivation



Cao X, Yue T, Yuan X, Dai, Q, L. Carin and D. Brady
 Snapshot Spectral Cameras: Towards Dynamic Capture of the Spectral World
IEEE Signal Processing Magazine, Vol.33, No.5, pp.95-108, 2016

科学问题及难点 Challenge

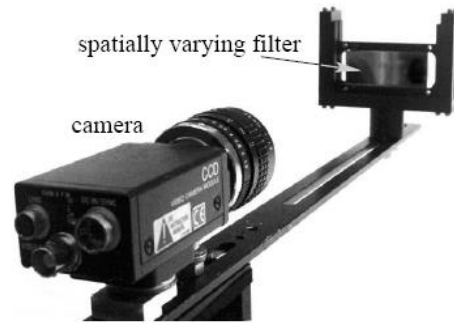


S.Nayar et al. PAMI '02



S.Nayar

美国两院院士 Columbia Univ.



时序变化滤波片
Spatially varying filter

高维光谱信号

空间 Spatial(x,y) * 光谱 Spectral(λ)
* 时间 Temporal(t)
1秒 ≈ 2 TB

传统光谱仪 (点扫描, 线扫描, 时序滤波)
Traditional Spectrometer (Scanning)

时间 <-> 光谱 Trading time for spectrum

- 采用时序或者空间扫描光谱
Spatial or temporal scanning
- 局限: 无法获取视频信息, 价格昂贵
Shortcomings: Incapable of capturing dynamic scenes, expensive

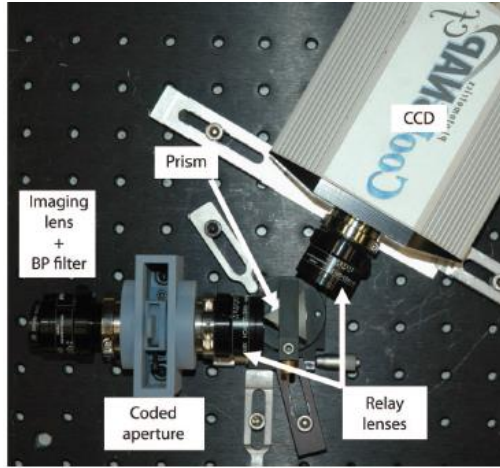
国内外研究现状 Related Work



D.Brady
IEEE&SPIE&
OSA Fellow

□ 编码光圈

Coded Aperture
Snapshot Spectral
Imager
CASSI
SPIE' 2009

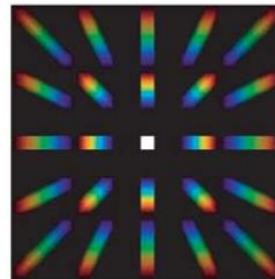
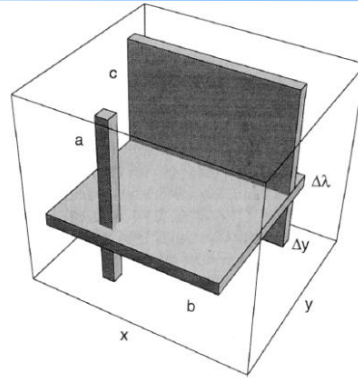


E. Dereniak
SPIE& OSA
Fellow

□ 断层扫描

Computed
Tomographic
Imaging
Spectrometer

CTIS
JOSA' 2008



重构法

系统特性和存在问题

2D拍摄 + 重构光谱

2D Imaging + reconstruction

- **光谱分辨率** Spectrum resolution: 6 nm
- **空间分辨率** Spatial resolution: 10,000 pixels
- **时间分辨率** Temporal resolution:
拍摄实时 Real time imaging
后期重建 Time-consuming reconstruction
- **局限** Shortcoming:
空间分辨率受限 Limited spatial resolution
引入重构误差 Limited accuracy
系统校准困难 Difficult to calibrate

PMIS光谱视频相机

PMIS Spectral Video Camera

2007~2010: Prism-Mask Imaging Spectrometer: PMIS¹

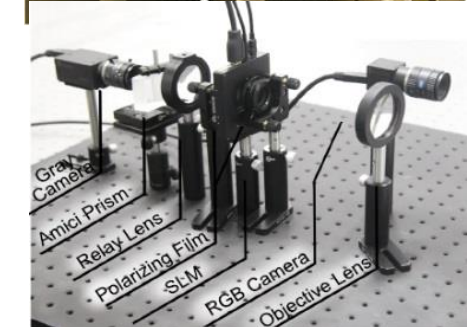
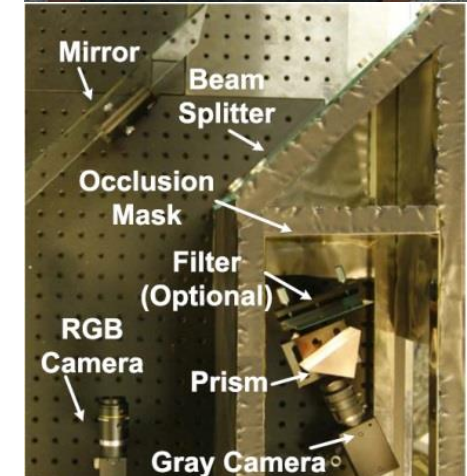
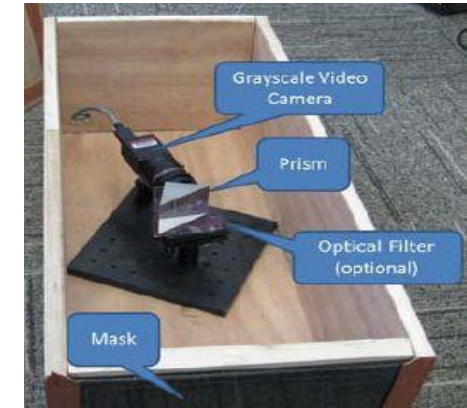
- 直接采集多光谱的视频信息
Directly capture multispectral video
- 低成本
Low cost
- 简单的装置和标定
Easy setup and calibration

2011~2014: PMIS²

- 同时具有高光谱分辨率和高空间分辨率
Both high spectral and spatial resolution
- 实时高光谱视频获取
Real-time hyperspectral video capture

2014 ~ 今 : PMIS³

- 场景自适应
Space-time modulation adaptive to the scene content
- 时空调制：提升精度和效率
Improved accuracy and efficiency

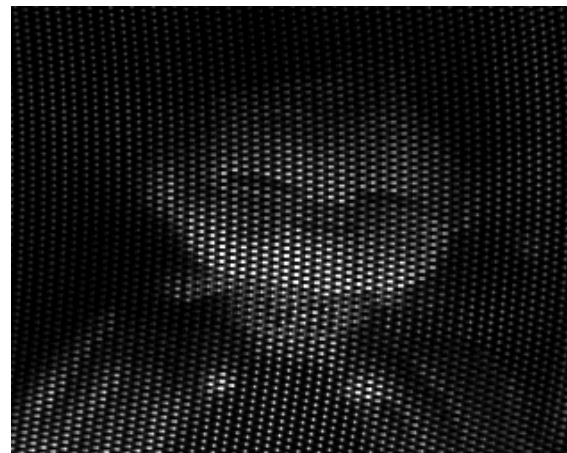
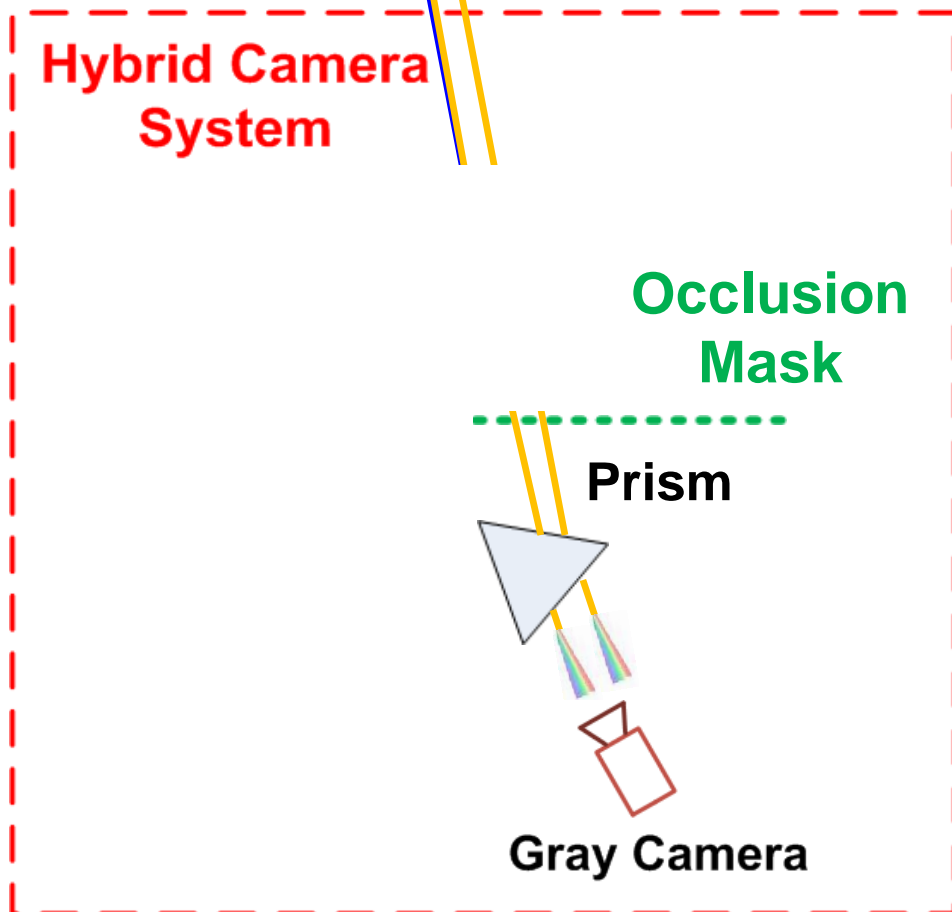


PMIS¹



Gray Camera

Low-Spatial
High-Spectral
Resolution Video

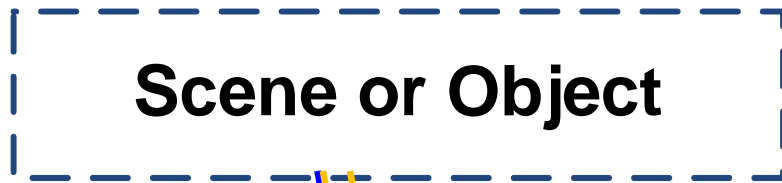


RGB Camera

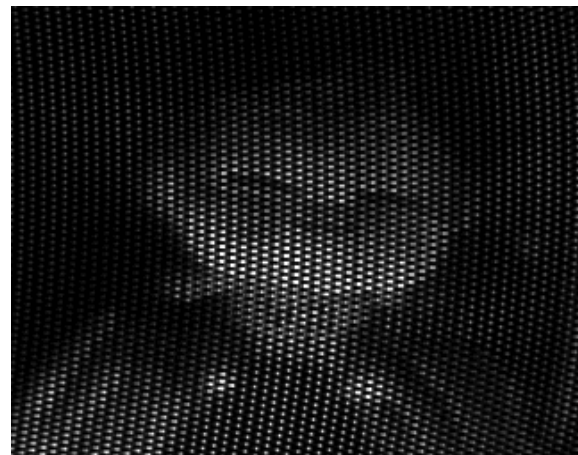
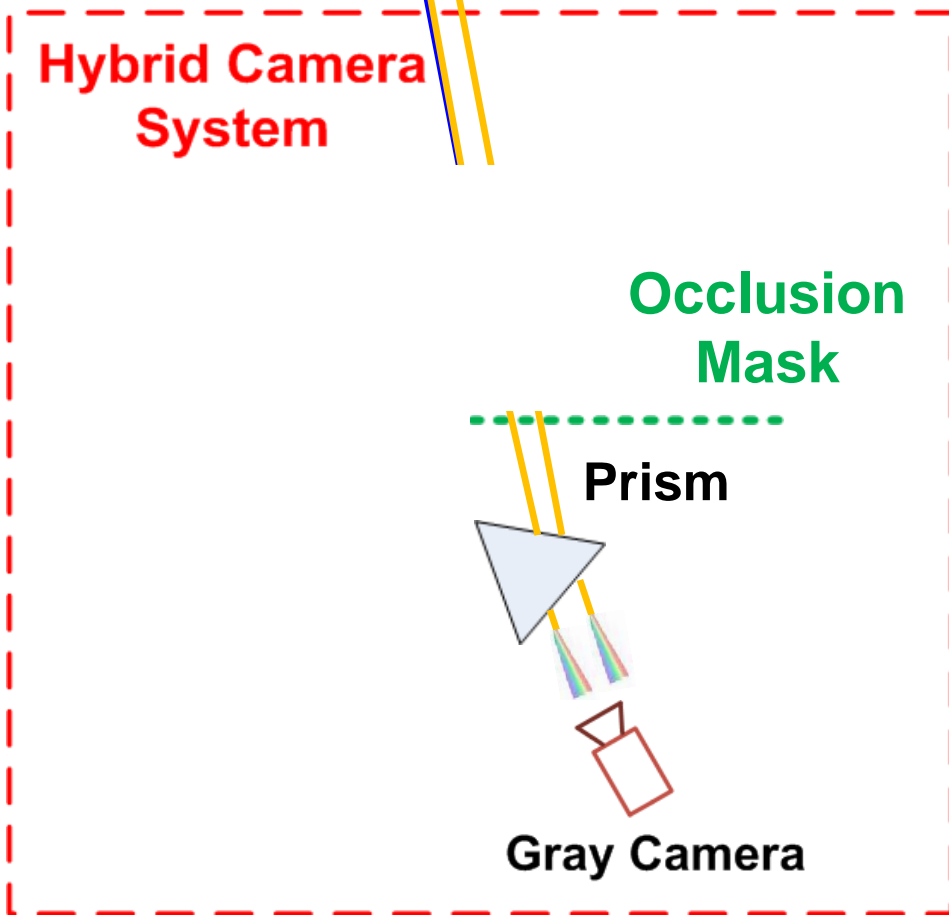
High-Spatial
Low-Spectral
Resolution Video

PMIS²: Hybrid Camera System

PMIS²



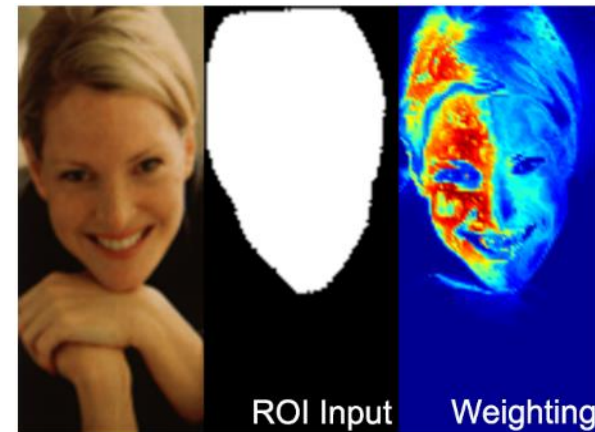
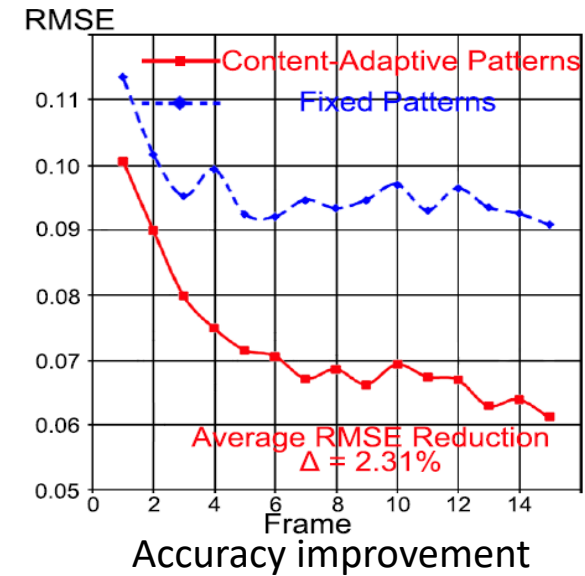
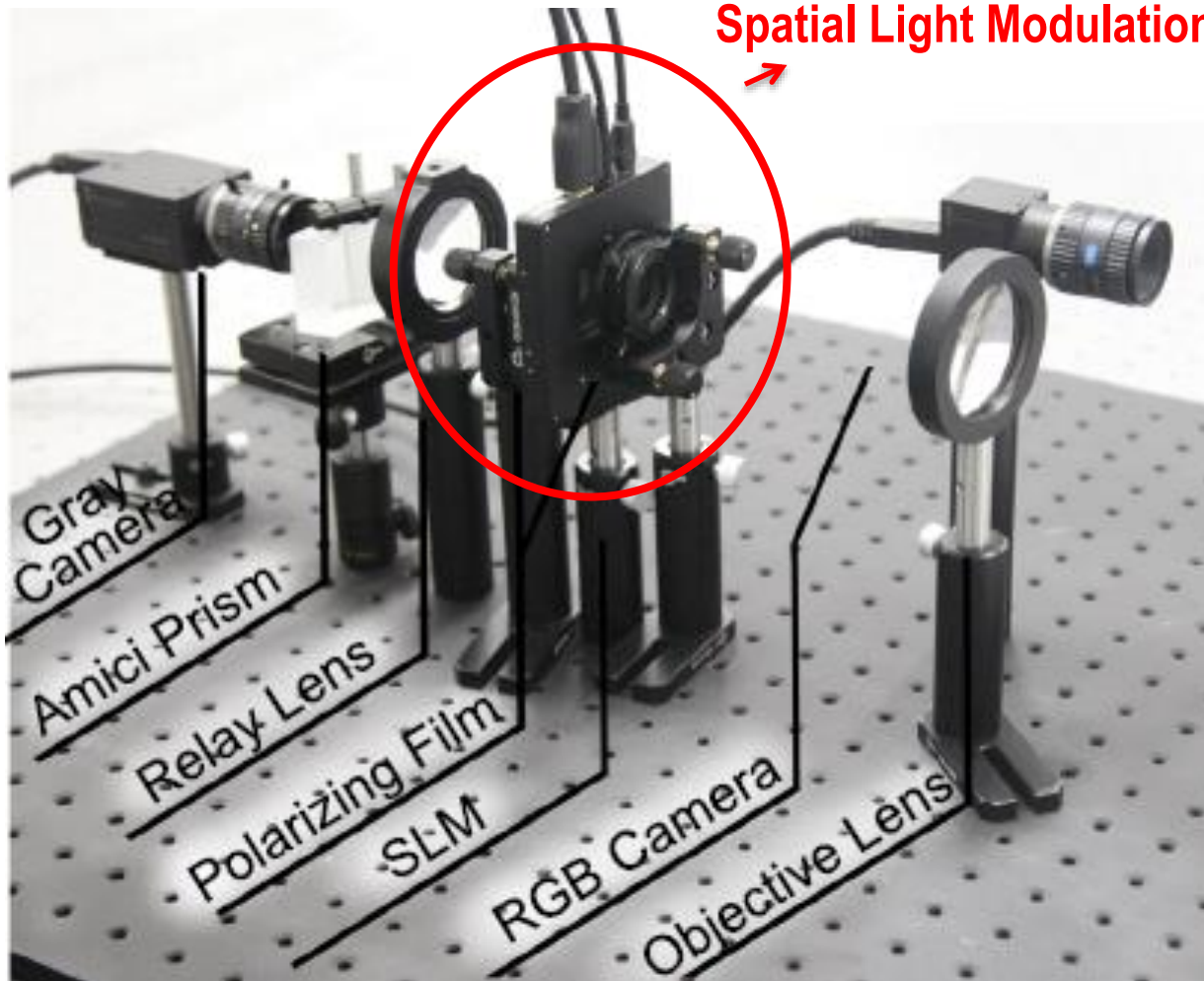
 Gray Camera Low-Spatial
High-Spectral
Resolution Video



 RGB Camera High-Spatial
Low-Spectral
Resolution Video

PMIS²: Hybrid Camera System

PMIS³ Prototype and Capturing Results



Targeted spectral acquisition by annotating regions of interest

PMIS³: Content-Adaptive High-resolution Spectral Video Acquisition

Optics Letters, 39(15), pp.1464-1466, 2014

Optics Express, 22(16), pp.19348-19356, 2014

总结 Summary

- **PMIS: 光谱视频成像 High Resolution Spectral Video Camera**
 - vs 传统光谱仪: 瞬拍能力 Snapshot (光谱图像->光谱视频)
vs Traditional Spectrometer: Snapshot Capability (Video)
 - vs CTIS / CASSI:
 - 实时视频输出 Real-Time Video Output
 - 低重建误差 Low Reconstruction Error
 - 低光学系统复杂度 Simple Optical Structure
- **PMIS相机采集的光谱视频数据集**



Ma C, Cao X, Dai, Q, et al. IJCV 2014



光谱观测软件

Computational Imaging Technology & Engineering Lab


Data Available@ <http://cite.nju.edu.cn>

x

CITE Home People Researches Publications

INTRODUCTION

Lab for Computational Imaging Technology & Engineering is a member of electronic science and technology department, Nanjing university. The research field covers Multispectral video acquisition, 2D-3D conversion and light field reconstruction.



News

- Our papers accepted to IEEE Conference on Computer Vision and Pattern Recognition(CVPR) 2015.
- Our papers accepted to IEEE Transactions on Image Processing(TIP) 2015.
- Our papers accepted to International Journal of Computer Vision(IJCV) 2014.
- Our papers accepted to Optics Letters(OL) 2014.
- Our papers accepted to Optics express(OE) 2014.

Links

- [ESE School of Nanjing University](#)
- [BBNC Lab of Tsinghua University](#)
- [Nanjing University](#)

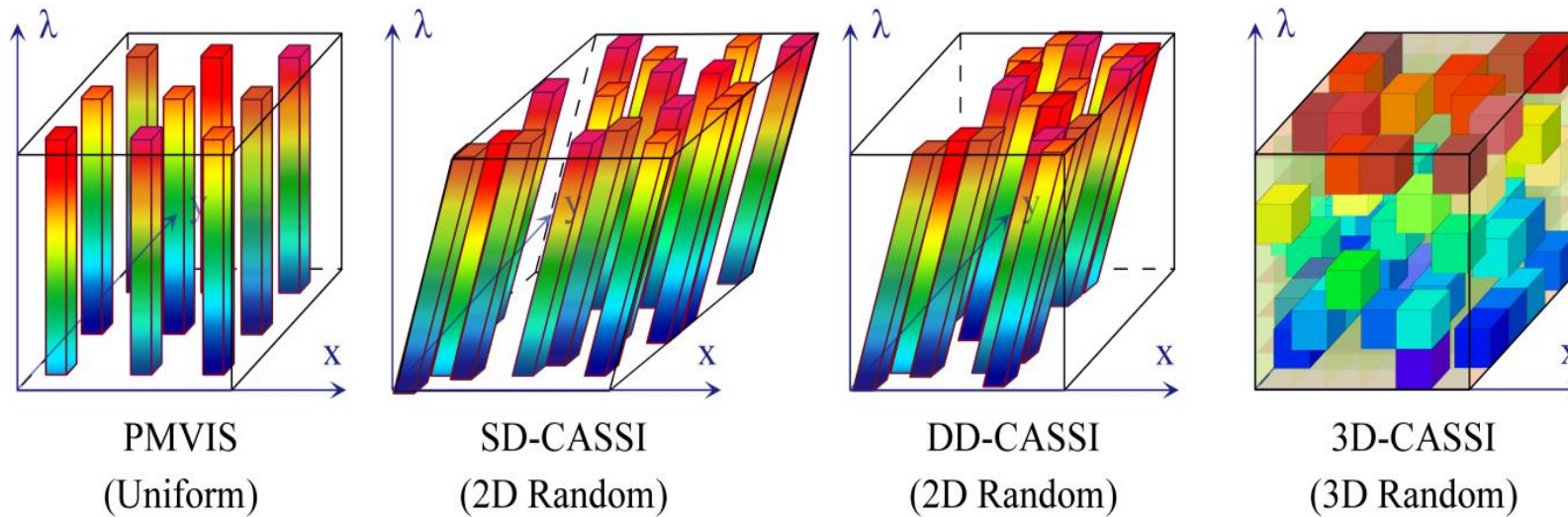
The big data problem of spectral video capture



Compared with CASSI

(Prof. D. Brady, Duke University)

More efficient capture strategy of 4D spectral data cube



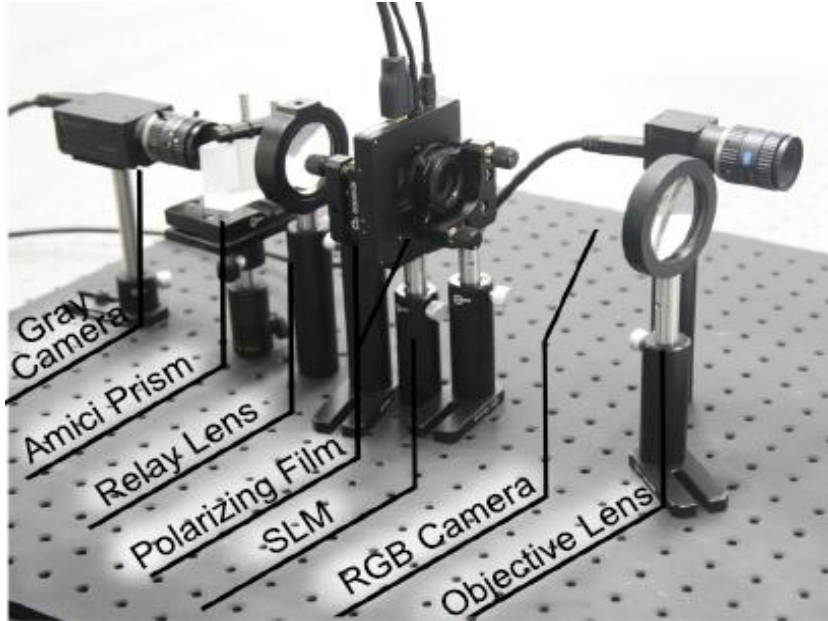
Cao X, Dai, Q, L. Carin and D. Brady

Snapshot Multispectral Cameras: Towards Dynamic Capture of the Spectral World

IEEE Signal Processing Magazine, Vol.33, No.5, pp.95-108, 2016 (IF: 6.67)

PMIS光谱视频相机

Prism-Mask Imaging Spectrometer



原型系统
Optical Principle



样机
Prototype camera (now)



Us Patent: High Resolution Multispectral Image Capture, US.20140085502

China Patent: A Computational Multispectral Computing Method, ZL201110212923.X, etc.

2011 EuroGraphics State-of-the-art (STAR) Report

2016 Reported by U.S. Air Force Lab as Representative Spectral Video Camera

The screenshot shows the Coral Spectral Analysis Software interface. It features a central camera view of a doll, a spectral curve plot, and a control panel on the right. Callouts in Chinese describe various functions:

- 相机控制与采集 camera control
- 像素点位置 Pixel Position
- 高光谱数据处理 spectrum reconstruction
- 绘制光谱曲线 Plot spectral curve
- 绘制单波段图像 monochrome image @ wavelength
- 绘制伪彩色图像 Synthesize pseudo-color image
- 像素点光谱曲线 Spectral curves

The spectral curve plot shows Intensity (0 to 0.3) versus Wavelength (400 to 700 nm). The control panel includes sections for Camera (Gain, Frr), Propagate (128, 128), Analysis (Spectral Curve, Monochrome Image, Pseudo-color Image), and Export.

Coral 光谱分析软件

“Coral” - Spectral Analysis Software

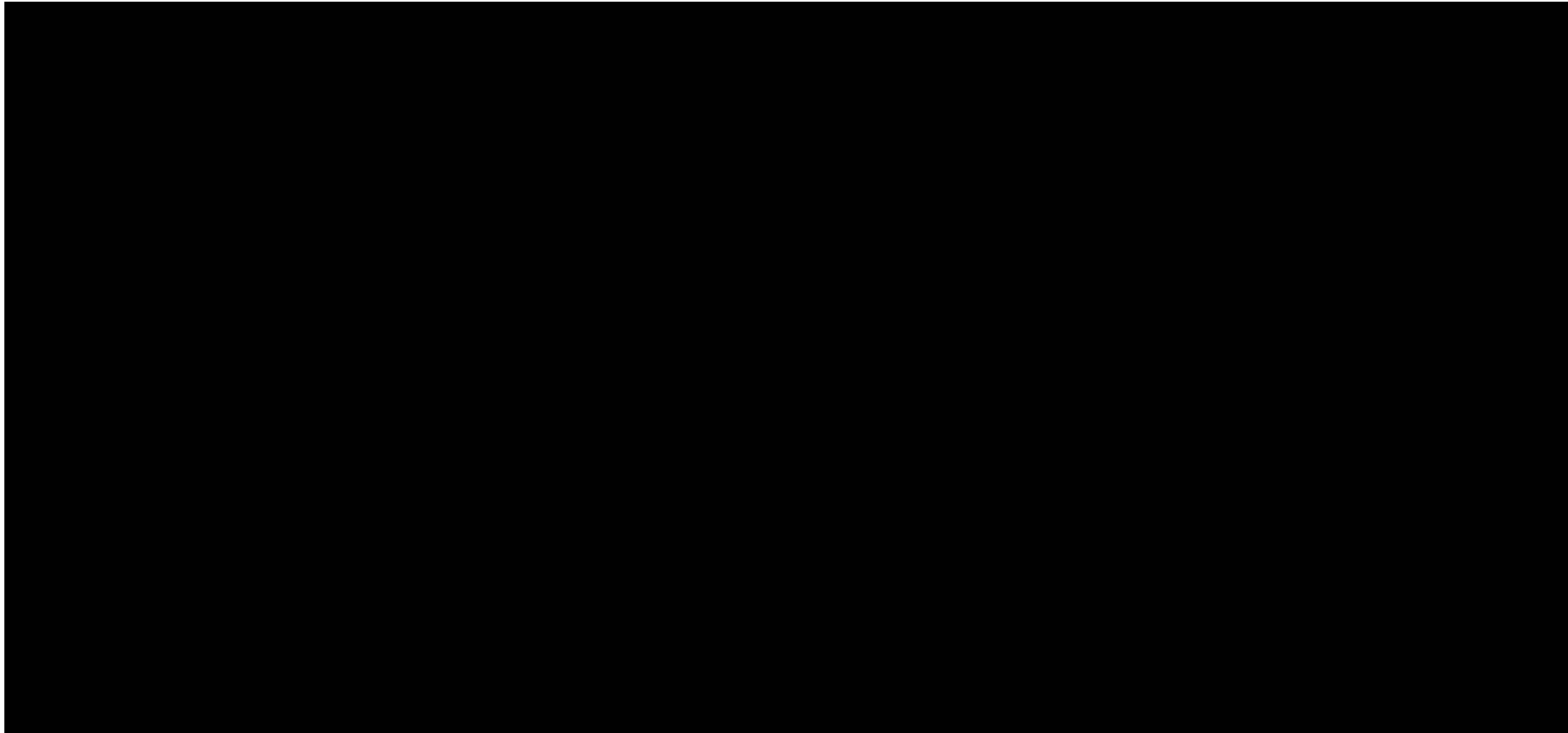
PMIS光谱视频相机 应用-1

PMIS Spectral Video Camera Demo-1

拍摄场景
Captured Scene

RGB视频
RGB Video

实时光谱动态曲线
Spectral curve



水质污染动态监测 Water Contamination Monitoring

PMIS光谱视频相机 应用-2

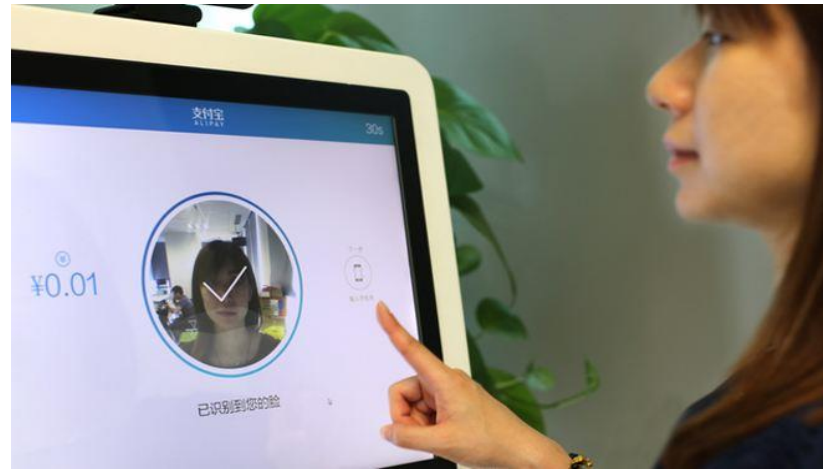
PMIS Spectral Video Camera Demo-2



智慧小区 Smart Home



手机 Cellphone



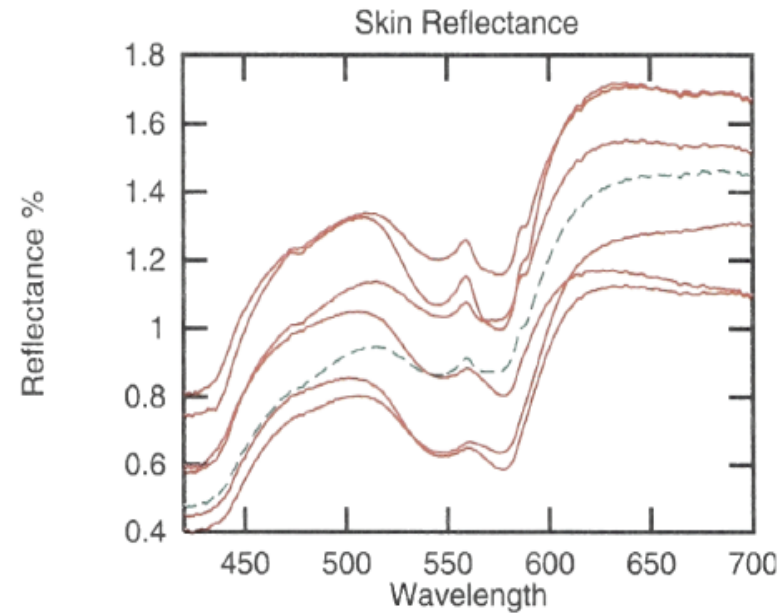
支付 Pay



高铁 Railway

Image Courtesy: iPhone X, 支付宝 (Alipay), 百度 (Baidu)

□ 人类皮肤反射的 Human skin with "W" Pattern [Angelopoulos' 01]



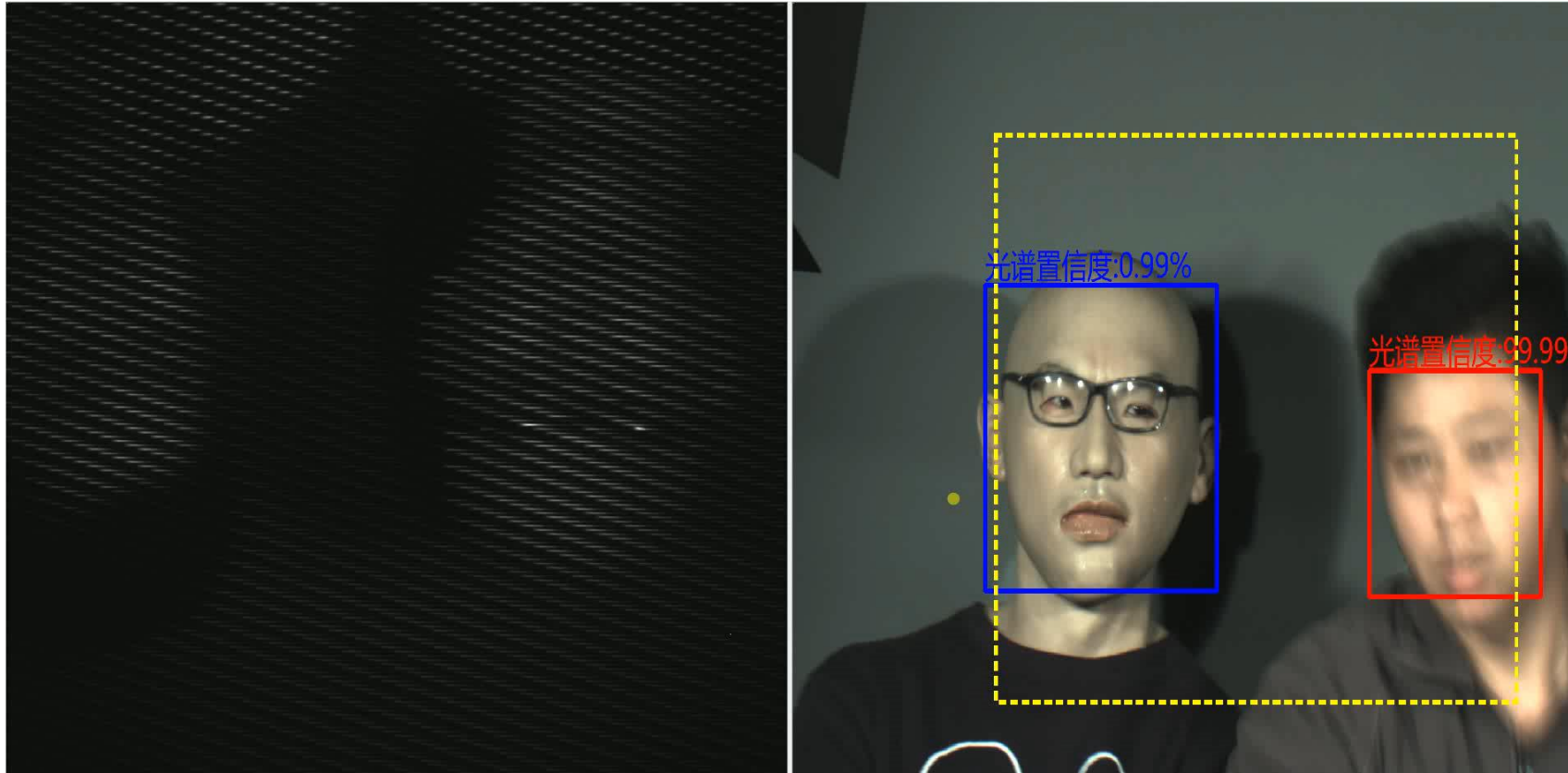
真假人脸识别 Real face identification

PMIS光谱视频相机 应用-2

PMIS Spectral Video Camera Demo-2

光谱视频
Spectral Video

识别效果
Tracking Result



真假人脸识别 Real face identification

PMIS光谱视频相机 应用-3

PMIS Spectral Video Camera Demo-3



PMIS光谱视频相机 无人机平台 UAV platform

PMIS光谱视频相机 应用-3

PMIS Spectral Video Camera Demo-3



光谱相机
Spectral camera



高分辨率光谱视频采集
High resolution spectral
video capture

数据压缩板
Data compression



光谱大数据实时压缩
Real-time data
compression

远距图传芯片
Transmission Unit



大范围实时传输
Long distance
data transmission

机载GPS
GPS Unit



高精度空间定位
High precision
positioning

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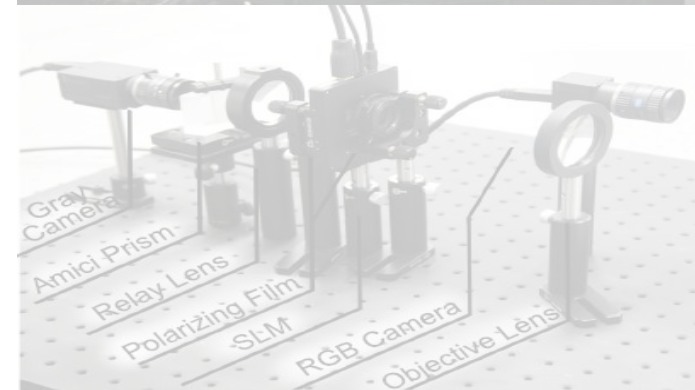
□ 颜色维度 Towards Color Dimension

- 高分辨率光谱视频相机: **PMIS**

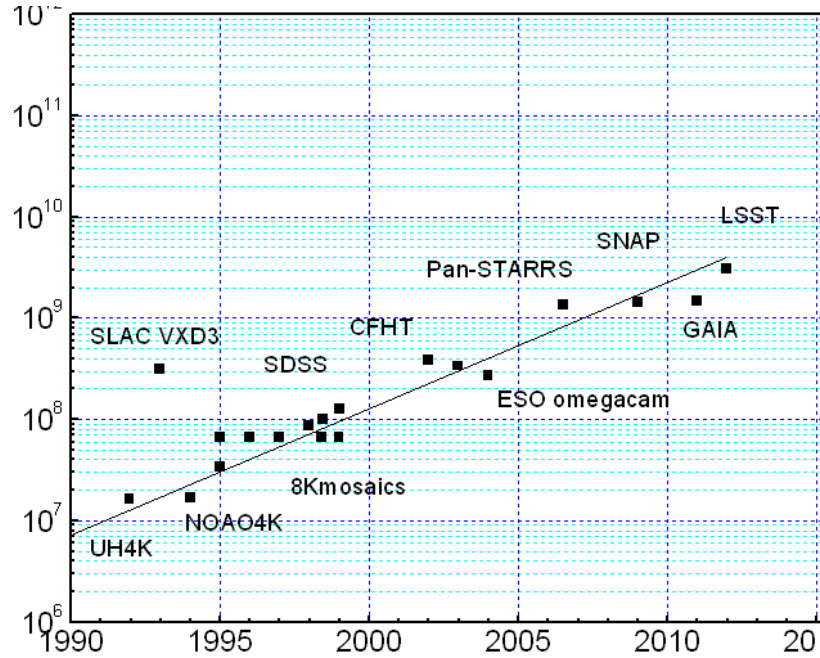
High resolution spectral video camera: **PMIS**

□ 空间维度 Towards Spatial Dimension

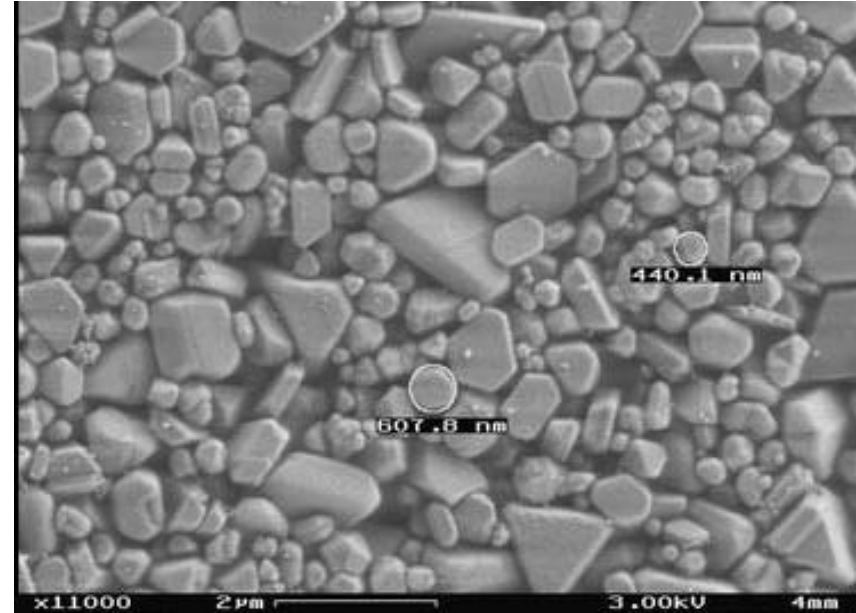
- 十亿像素成像 Gigapixel imaging system



问题背景 Background



成像像素数-发展趋势 (摩尔定律)
Moore's Law



柯达胶片溴化银颗粒SEM照片
(分辨率~1微米)

SEM photo of Kodak film silver bromide particles
(spatial resolution ~ 1µm)

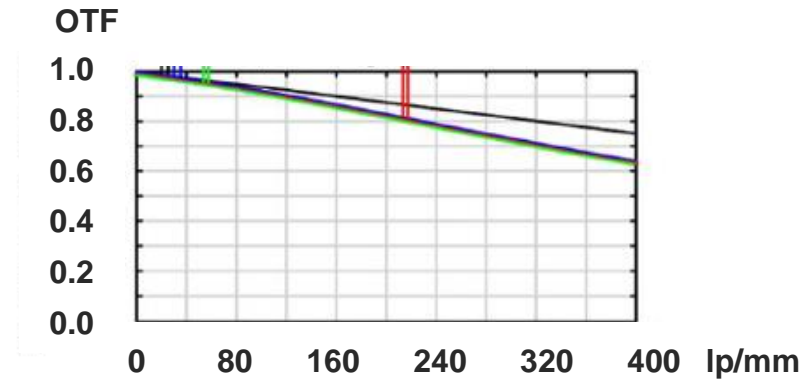
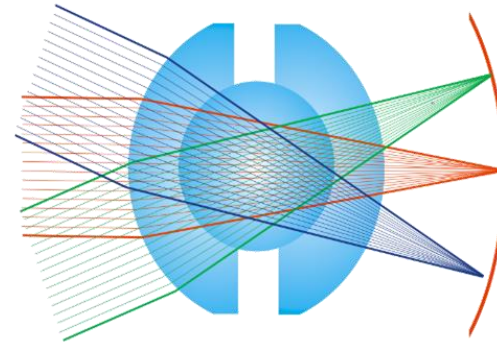
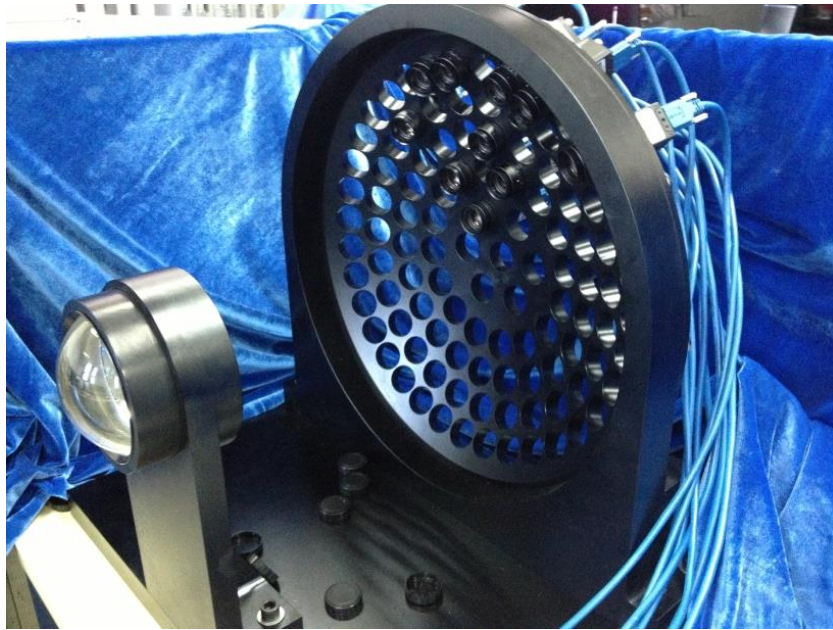
如何实现10亿像素成像

How to fulfill Gigapixel Imaging

多相机系统：十亿像素

Camera Array: Gigapixel imaging

Hats off: Prof. David Brady



设计双半球镜组，分辨率高达600lp/mm
 Double hemispherical mirror with resolution up to 600lp/mm

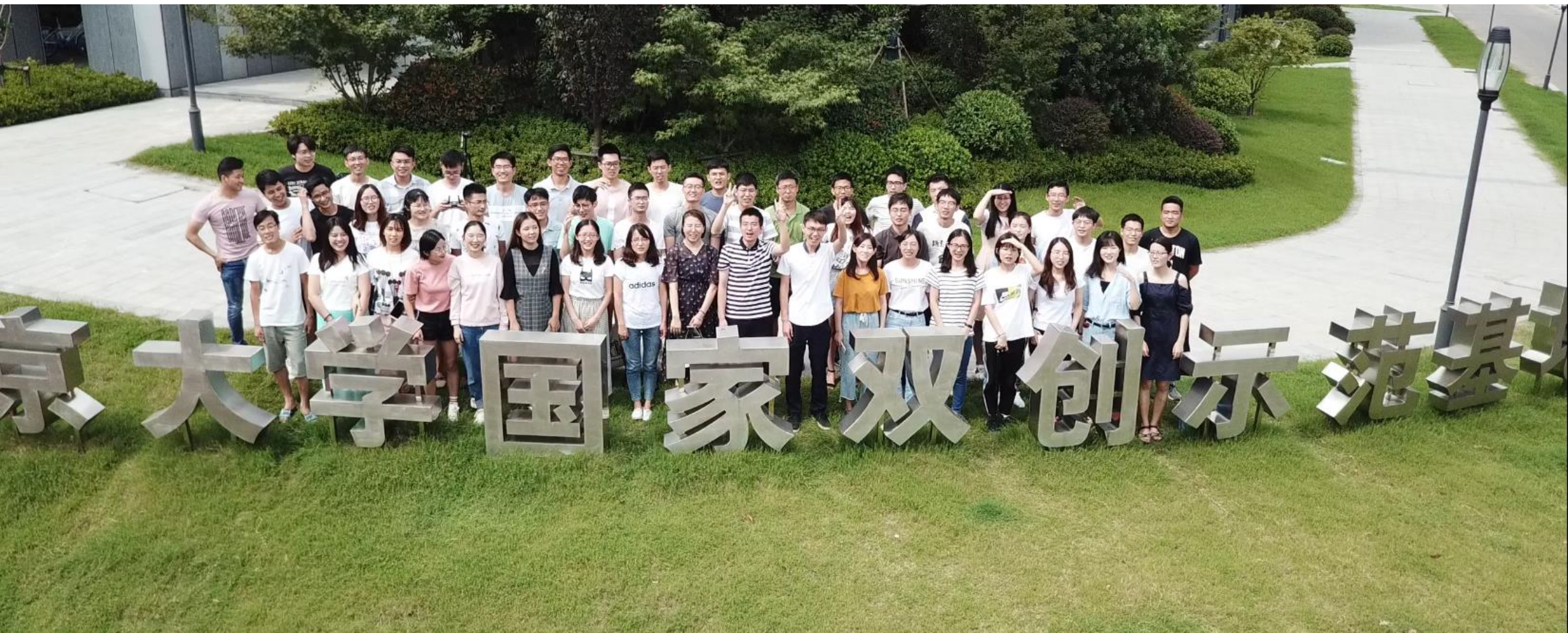
- **球型物镜微相机阵列级联模型** Sphere type objective micro-camera array cascade model
- **多通道图像配准技术** Multi-channel image registration
- **动态实时高图像分辨率成像** Dynamic real-time high image resolution imaging

构建完成由118个微相机构成的曲面级联计算光场成像系统(宽视野：100 × 60度)

Build up a cascaded light field imaging system consisting of 118 micro cameras (wide field of view: 100 × 60 degrees)

CITE

Computational Imaging Technology & Engineering



欢迎指导 南京大学 CITE 实验室！
Welcome !

谢谢!
Thanks!