



Insegnamento di

**CHIRURGIA ASSISTITA DAL CALCOLATORE E
INFORMATICA MEDICA**

**Corso di Laurea in Ingegneria Biomedica
Vincenzo Ferrari**

[Realtà Aumentata in Chirurgia](#)

Many thanks to: Fabrizio Cutolo, MSc, PhD



SCOPIS
medical

Professor Oliver Kaschke, Berlin

Scopis TGS® - Target Guided Surgery

Clinical Case: Frontal Sinus Right Side

www.scopis.com





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Realtà aumentata

Da Wikipedia, l'enciclopedia libera.

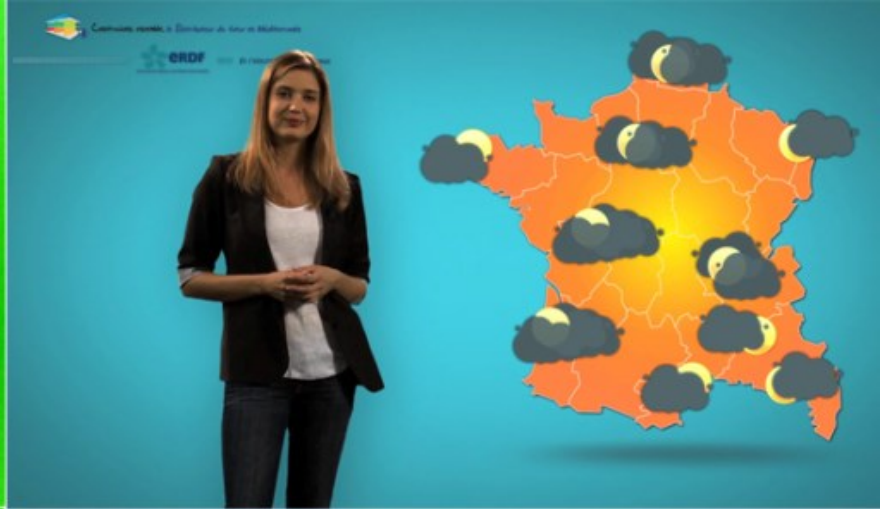
Per **realtà aumentata** (o **realtà mediata dall'elaboratore** in inglese **augmented reality**, abbreviato "AR"), si intende l'arricchimento della percezione sensoriale umana mediante informazioni, in genere manipolate e convogliate elettronicamente, che non sarebbero percepibili con i cinque sensi.^[1]

Il **cruscotto** dell'automobile, l'esplorazione della città puntando lo **smartphone** o la **chirurgia robotica** a distanza sono tutti esempi di realtà aumentata.

Indice [\[nascondi\]](#)

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Visual AR / AR Visiva



La realtà aumentata visiva arricchisce immagini del mondo reale con contenuti virtuali generati al computer.



Photo courtesy of Intergraph Government Solutions

Virtual data may be informative (i.e. textual or numerical values)

or

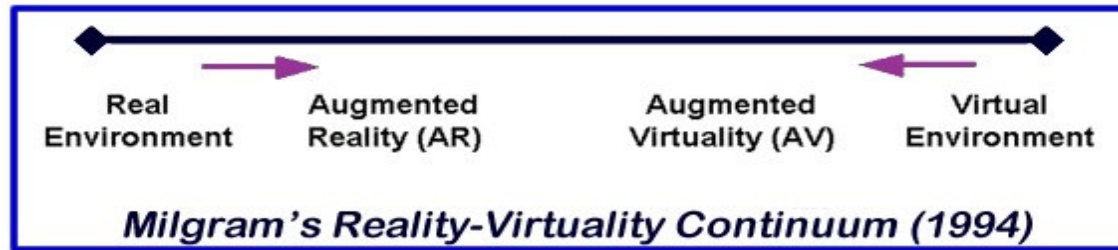
consist in 3D objects inserted in spatially coherent positions



Navab et al.



Defining Characteristics of AR



*“...The basic goal of an AR system is to enhance the users’ **perception** of and **interaction** with the real world through supplementing the real world with 3D virtual objects that appear to **coexist** in the same space as the real world” Azuma et al. 1997*

- It enhances perception (arricchisce la **percezione** sensoriale)
- It yields 3D registration of digital data to the real scene (fornisce **allineamento** coerente tra contenuto virtuale e scena reale in maniera tale che l’osservatore li percepisca come parte integrante della scena reale stessa)
- It provides real-time interactivity (garantisce un’**interazione** ergonomica e funzionale con la scena aumentata)

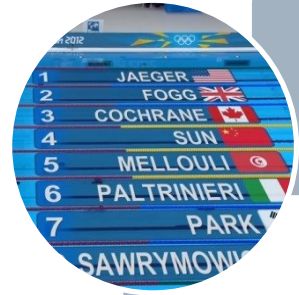
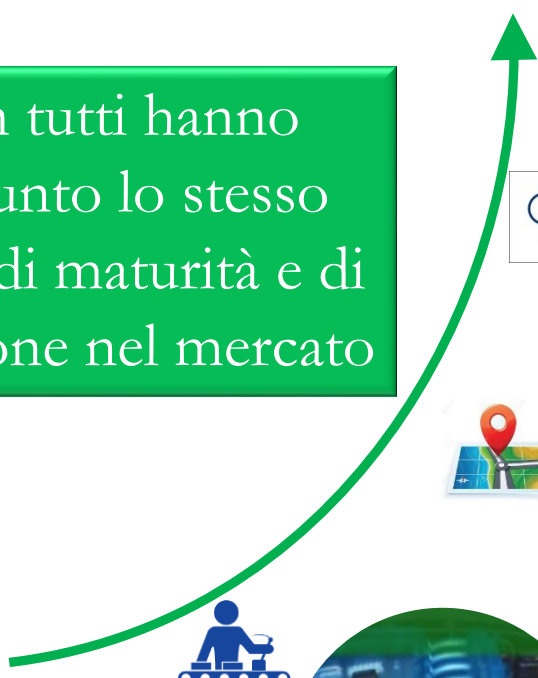


AR Fields of Applications



Time

Non tutti hanno raggiunto lo stesso livello di maturità e di diffusione nel mercato



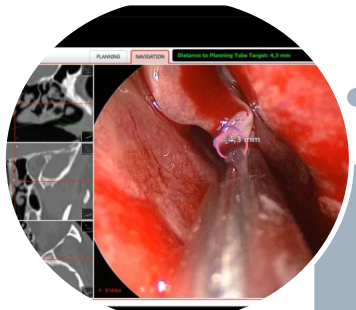
TV-Sports broadcasting



location-based mobile applications



Military & Manufacturing / Industria Militare e Manifatturiera



Healthcare & Education / Sanità e Istruzione

Sta iniziando ora ad entrare nel workflow chirurgico





AR in Manufacturing



Diverse aziende hanno provato ad introdurre la AR all'interno del processo produttivo, non solo per scopo dimostrativo o di marketing. La Boeing, in ambito aeronautico, è stata la prima all'inizio degli anni 90.





AR in Automotive Industry



Goal: Delivering instructions useful to drivers
AR come assistenza per parcheggio o guida

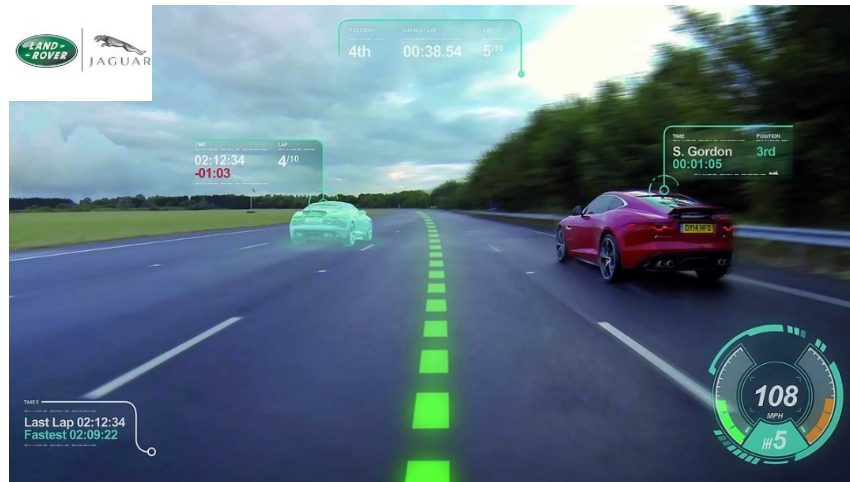
Head up Display



Parking assistance



➡ Standard Today



Concept and under development: AR
Windscreens, maybe in combination with
Vehicle-to-vehicle
communication protocols



AR in Sports (1)





AR in Sports (2)



AR can make an AC sailing race easy to follow as a football match.



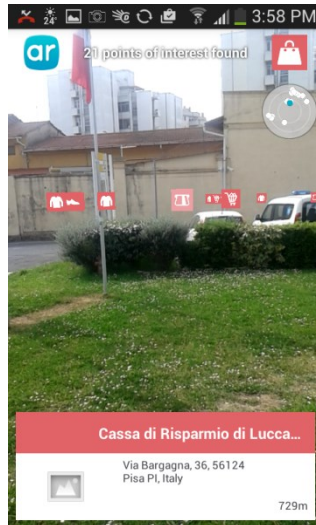
Elementi grafici come velocità dell'imbarcazione, percorsi di regata ideali, linee di partenza e di arrivo, percorsi attorno alle boe, etc. aiutano il pubblico a comprendere le fasi della gara.



AR in mobile applications

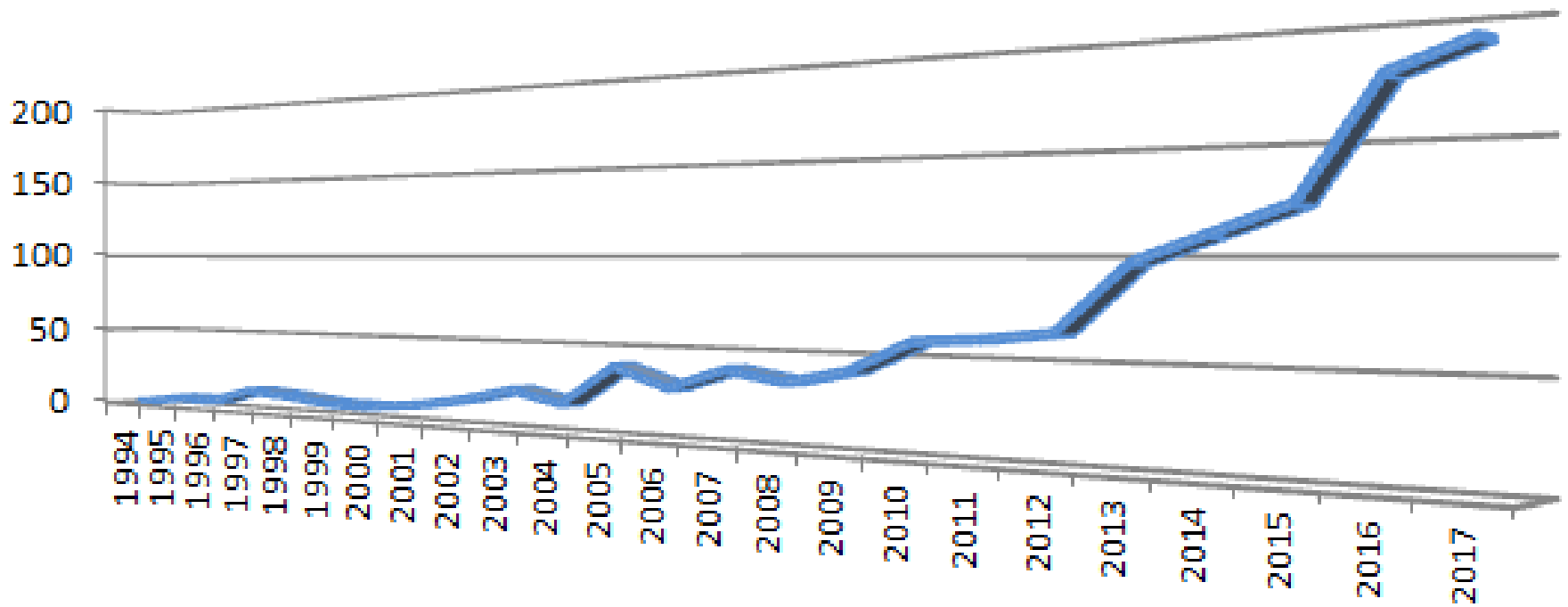


Localization-based (GPS+compass+accelerometer) mobile apps for Touristic info, restaurants, social networking (instagram, twitter, etc.), events...



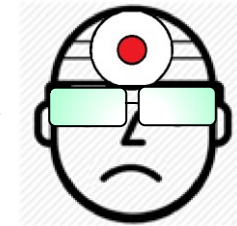


Publications indexed in Pubmed containing "augmented reality" OR "mixed reality" in the title or in the abstract





Primary Goal: Avoid Inflated Expectations...



...evitare di realizzare dispositivi troppo research-oriented e di «gonfiare» troppo le aspettative tra gli utilizzatori (medici)...

Few reasons why such systems are not yet routinely used in the operating room. Among the others, many works did not consider operational constraints (vincoli logistici in sala operatoria) and surgeons' needs and requirements (poca attinenza con esigenze cliniche).

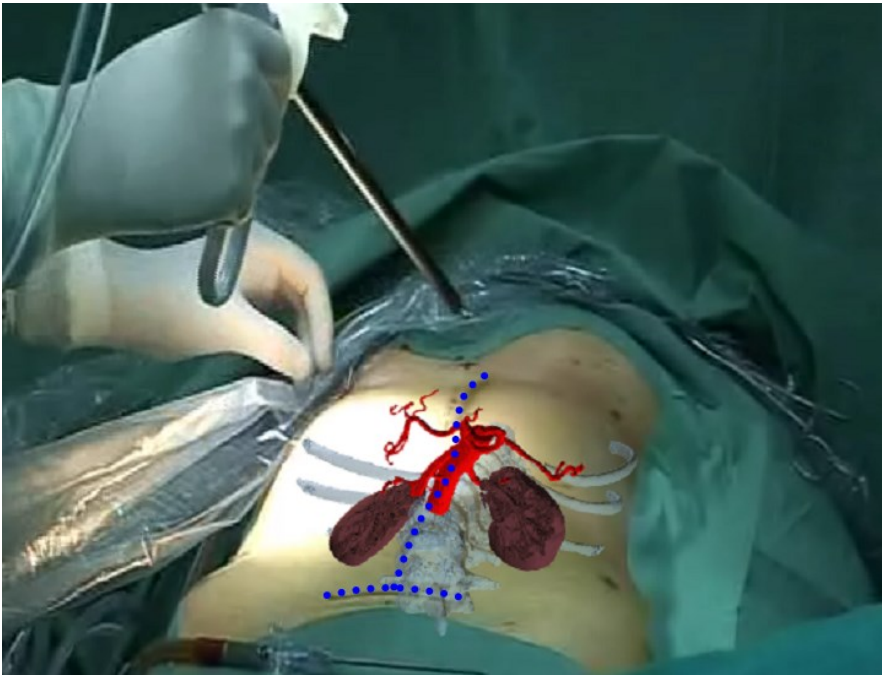


L'abilità di vedere all'interno del corpo umano e quindi trasferire la complessità dell'anatomia umana in una esauriente rappresentazione visiva è stata considerata storicamente da pittori e studiosi di medicina di primaria importanza.



Frans Denys, The Anatomy Lesson of Dr. Joannes van Buyten, 1648, oil on canvas.

Recentemente la disponibilità di sempre più complessi ed accurati sistemi di imaging medico e l'esigenza di ridurre l'invasività delle procedure chirurgiche hanno incoraggiato l'implementazione di modalità di visualizzazione 3D efficaci e realistiche.



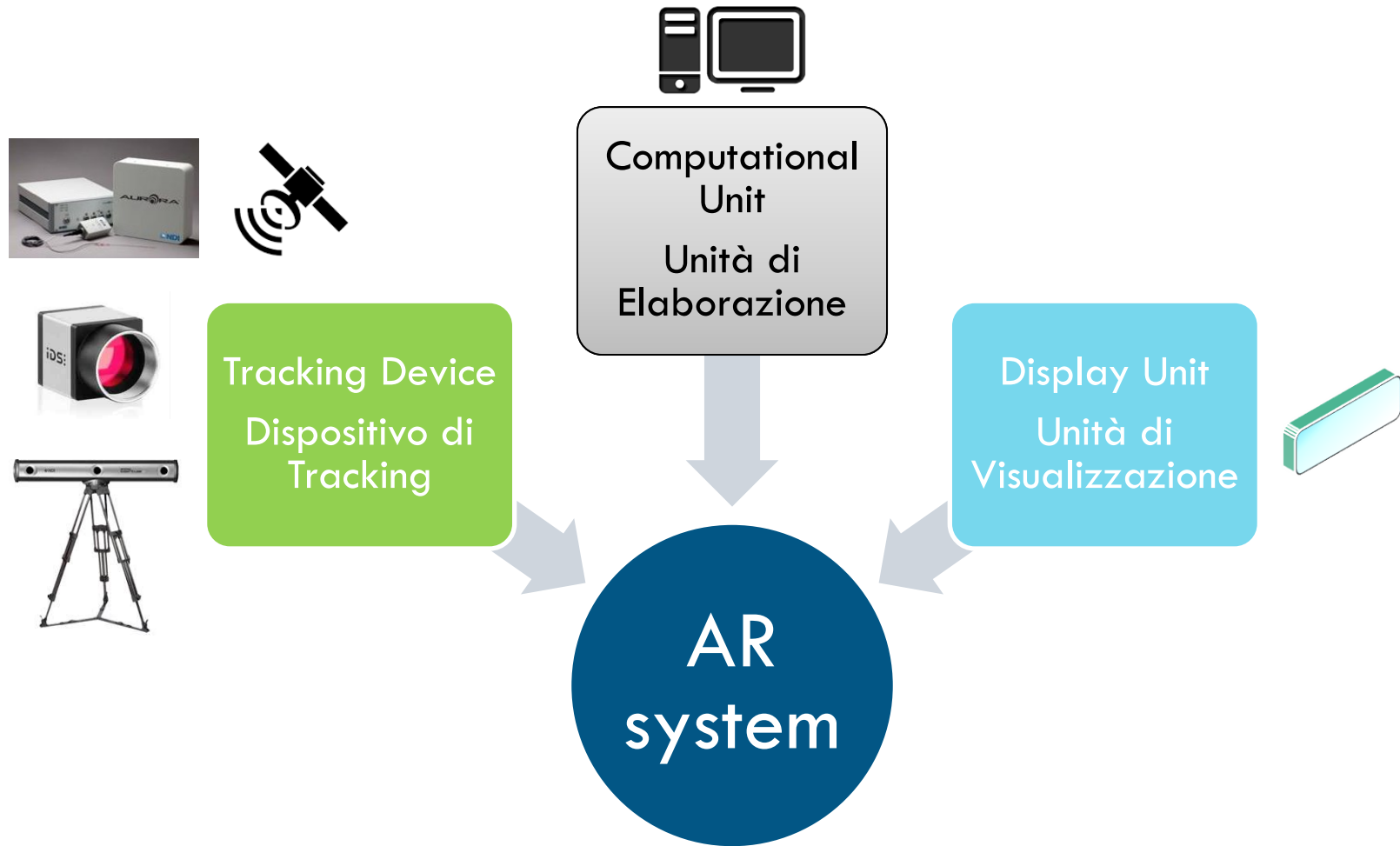
EndoCAS - Università di Pisa



CAMP - Technischen Universität München

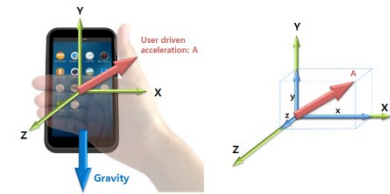


Key Components of AR systems





Tracking Types for AR systems



Mechanical Tracker

Magnetic Tracker

Optical Tracker

Gps Tracker

Inertial Tracker



Passive Markers

Active Markers

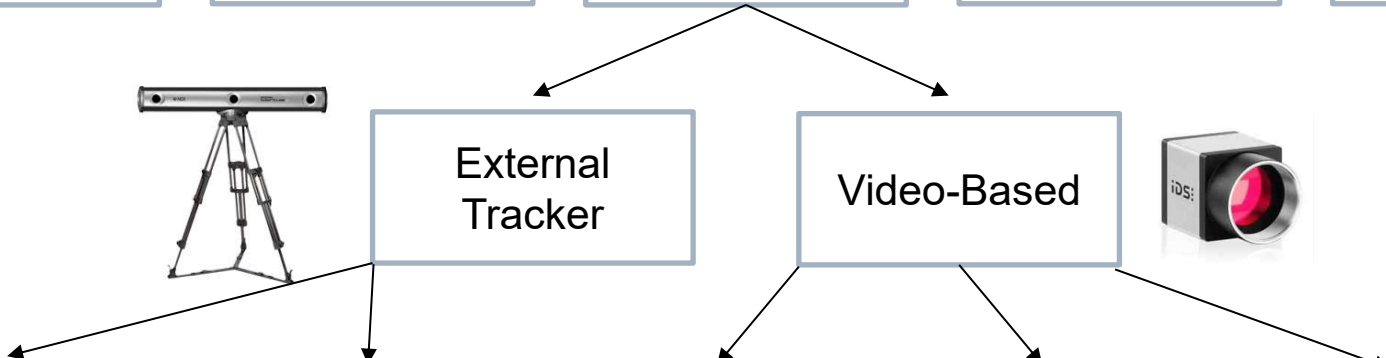
Marker-Based

Surface-Based
Edge-Based

Model-Based

External Tracker

Video-Based





Real Data source

Virtual Data source

Tracking modality

Registration technique

Visualization Processing

Display type

Perception location





Real Data source

Virtual Data source

Tracking modality

Registration technique

Visualization Processing

Display type

Perception location



Classification of AR Displays



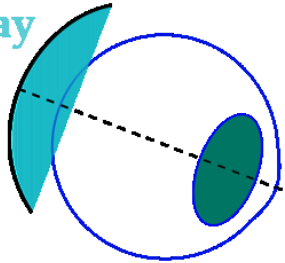
Head-attached

Hand-held

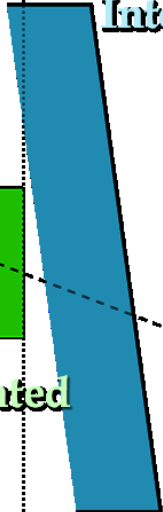
Spatial

*Ri-elaboration of Bimber et al. [1]:
Modern approaches to augmented
reality, 2006*

Retinal
display



Head-mounted
display

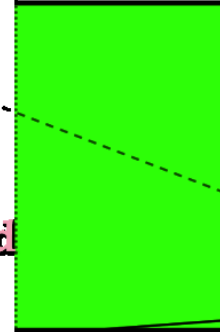


Head up display
Visore a «testa alta»
Integrato nell'elmetto
o parabrezza

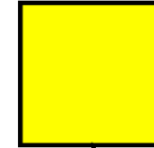


Hand-Held
display

Spatial display
Schermi fissi



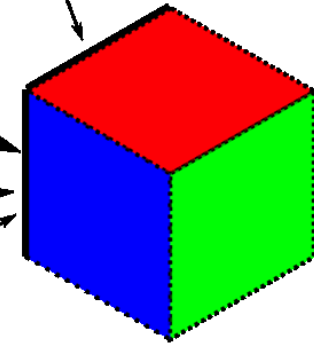
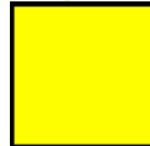
Projector



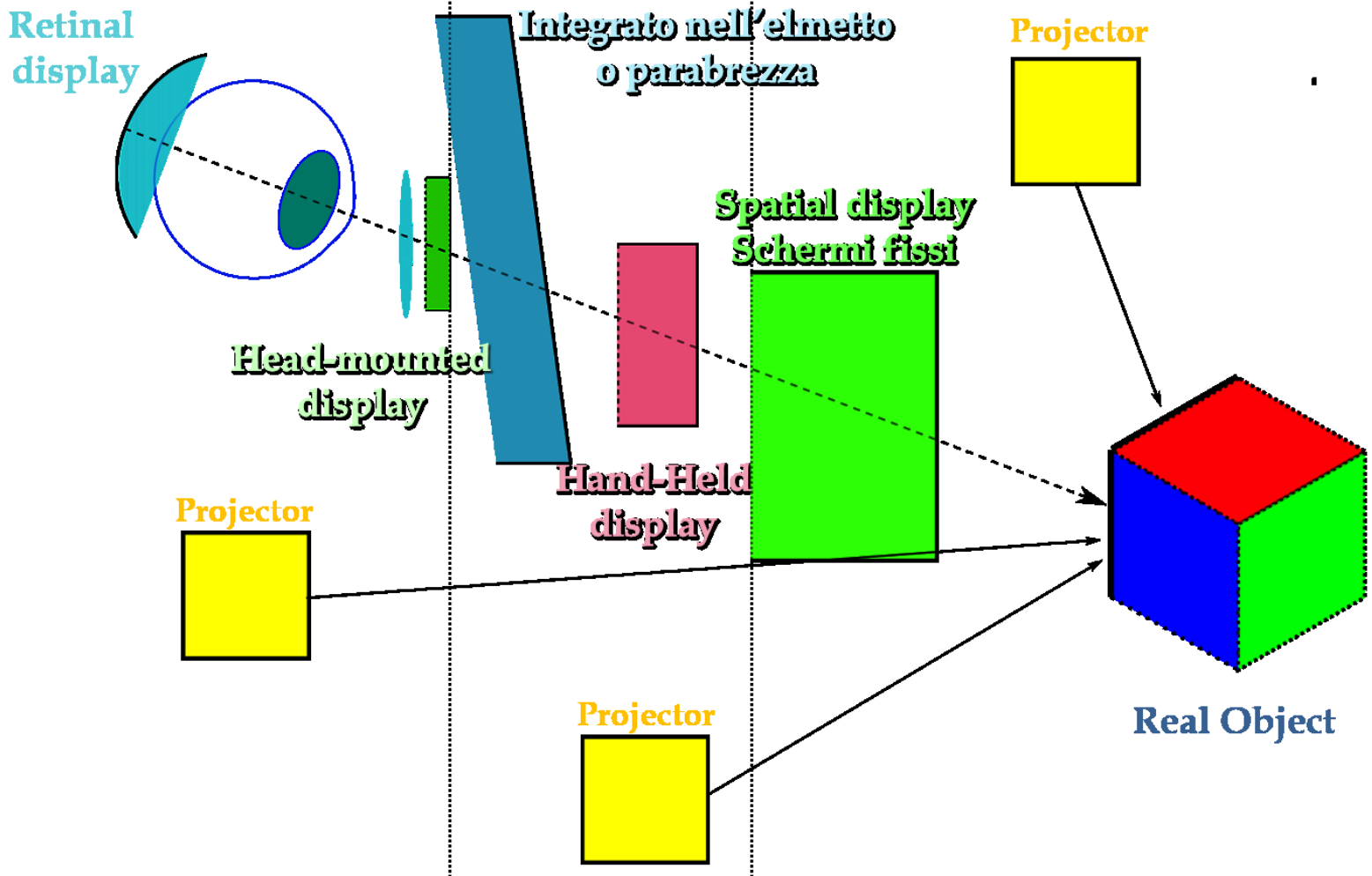
Projector



Projector

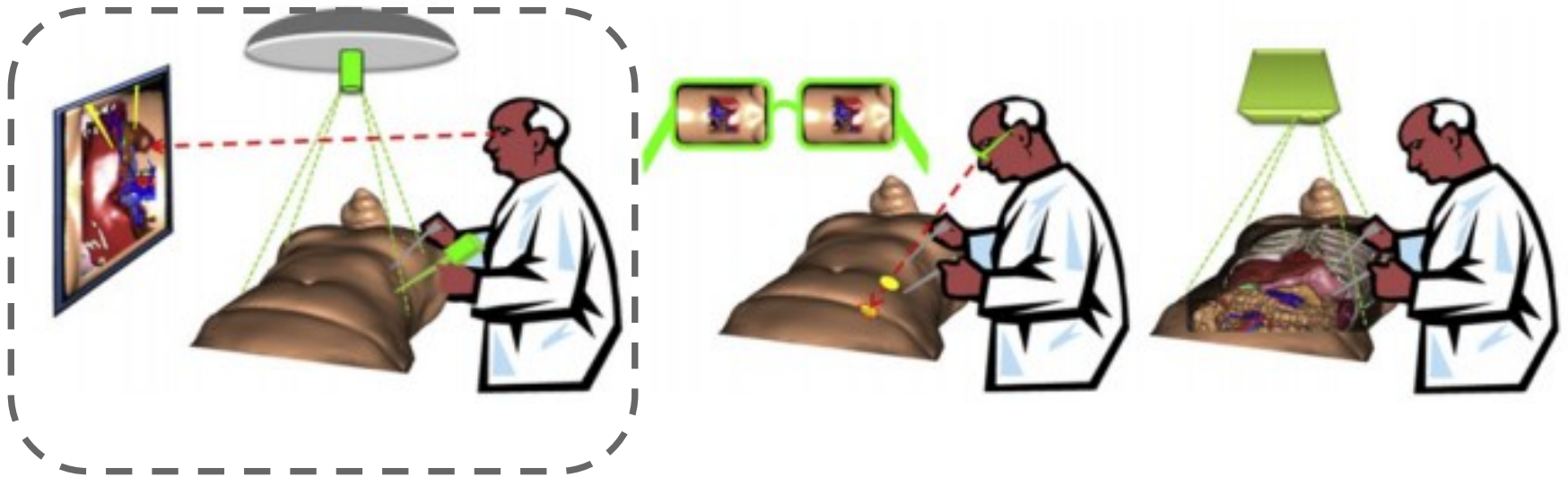


Real Object





S. Nicolau et al. / Surgical Oncology 20 (2011) 189–201





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medical

Professor Oliver Kaschke, Berlin

Scopis TGS® - Target Guided Surgery

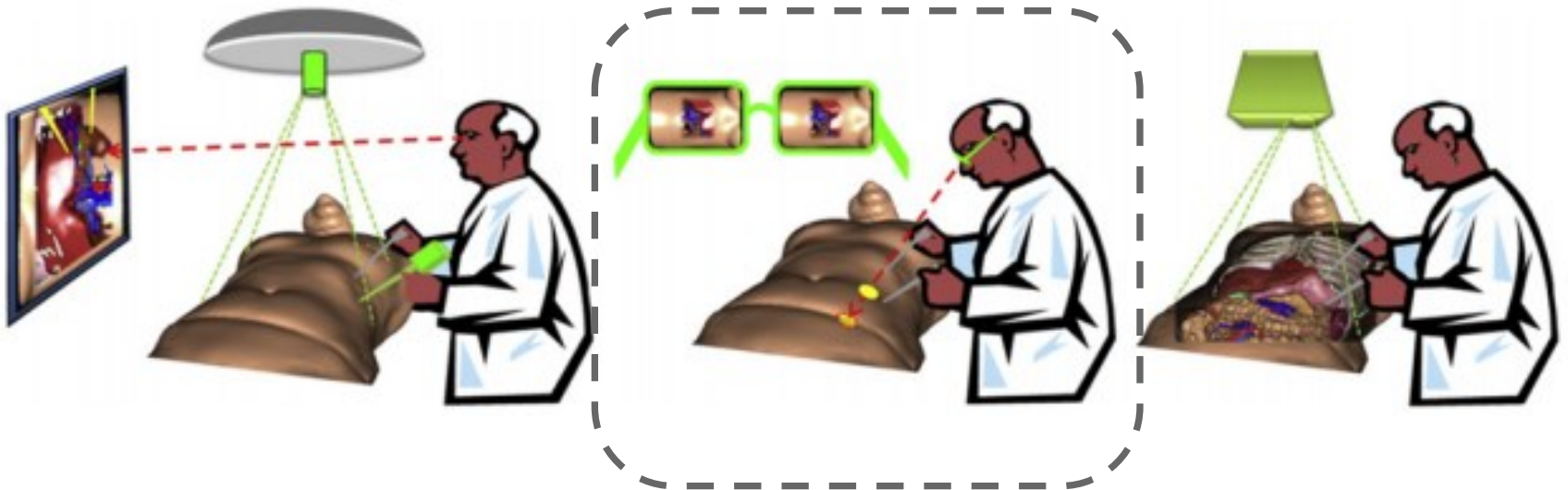
Clinical Case: Frontal Sinus Right Side

www.scopis.com





S. Nicolau et al. / Surgical Oncology 20 (2011) 189–201







Google

GOOGLE GLASSES SURGERY



Tutti Immagini Video Shopping Notizie Altro Impostazioni Strumenti







Google HOLOLENS SURGERY

Tutti Immagini Video Notizie Shopping Altro Impostazioni Strumenti



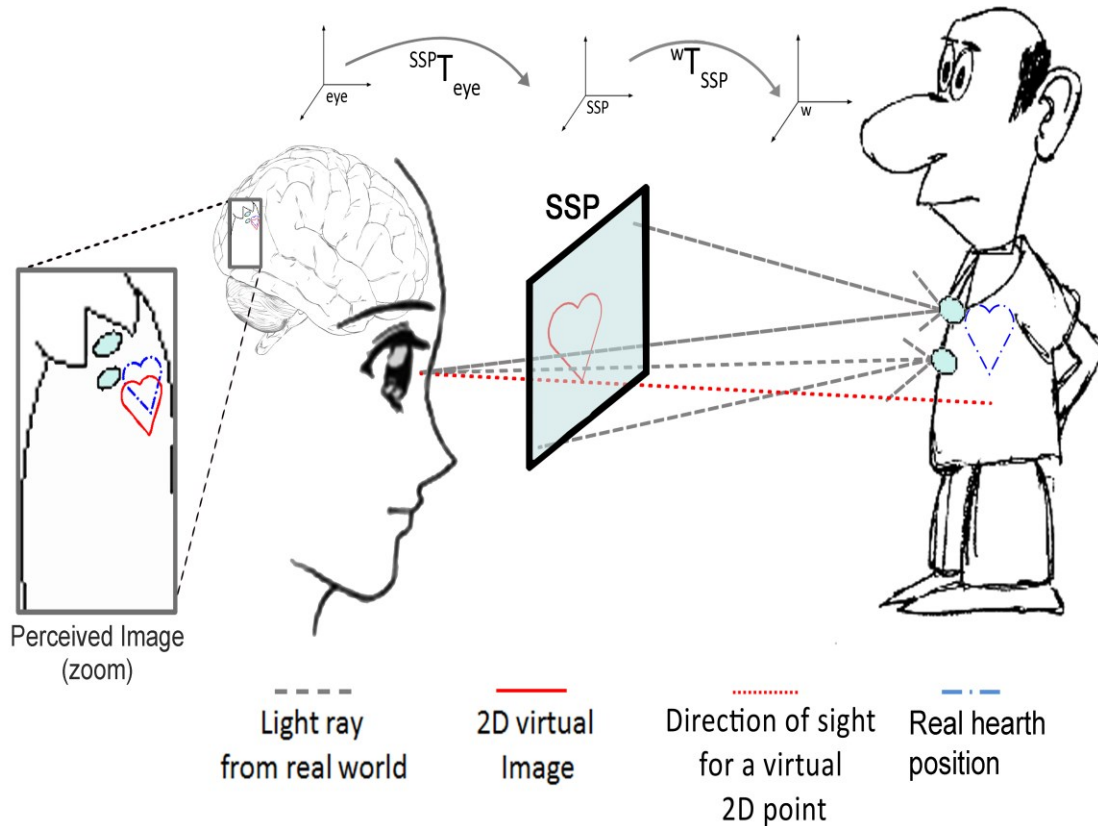


Optical See-Through AR display





Optical See-Through AR display



Natural view



User dependent calibration troubles





Geometric Calibration of Head-Mounted Displays and its Effects on Distance Estimation

Falko Kellner, Benjamin Bolte, Gerd Bruder, Ulrich Rautenberg, Frank Steinicke, Markus Lappe, and Reinhard Koch



Optical See-Through HMD Calibration: A Stereo Method Validated with a Video See-Through System

Yakup Genc[†]

Frank Sauer[†]

Fabian Wenzel[†]

Mihran Tuceryan[‡]

Nassir Navab[†]



Hololens Registration Accuracy



Registration goals



Static error
<10mrad

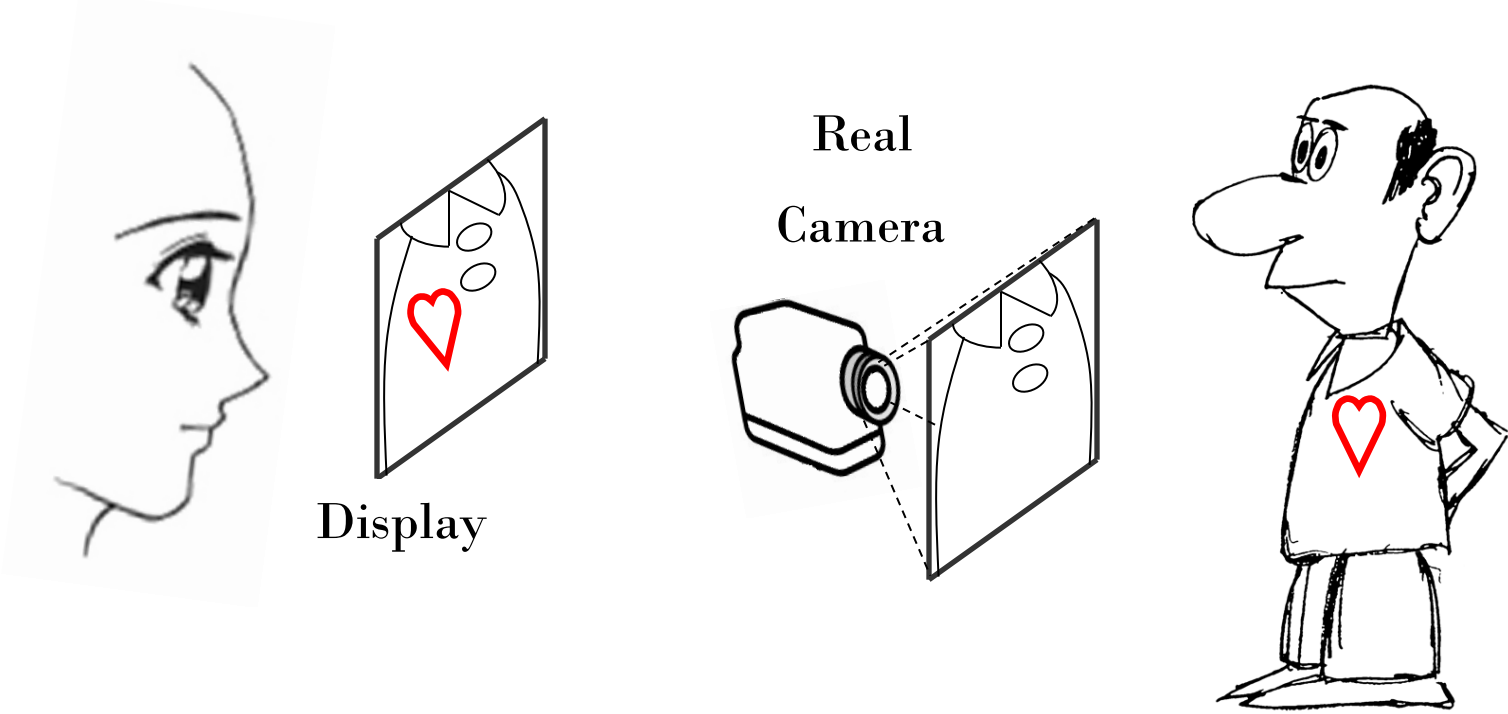


5mm at 50 cm





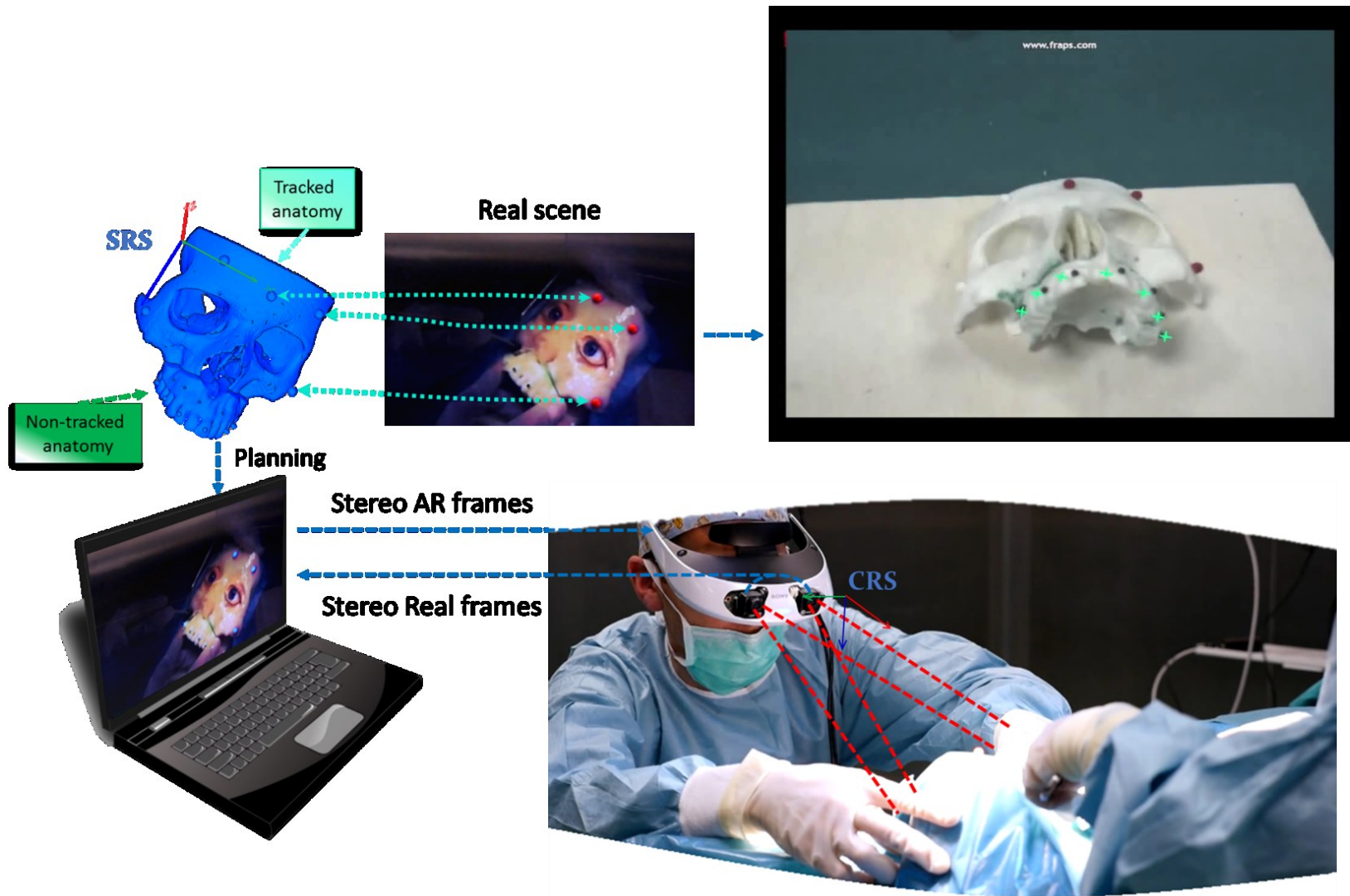
Video See-Through AR display



Camera mediated view



AR registration



"Badiali EtAl Augmented reality for maxillofacial surgery: validation of a wearable system for maxillary repositioning," *Journal of Cranio-Maxillofacial surgery*, 2014.



Examples of Optical & Video HMDs



OPTICAL SEE-THROUGH



Epson Moverio



Google Glasses



Lumus DK-32

VIDEO SEE-THROUGH



Vuzix WRAP 920AR



Visette45 SXGA



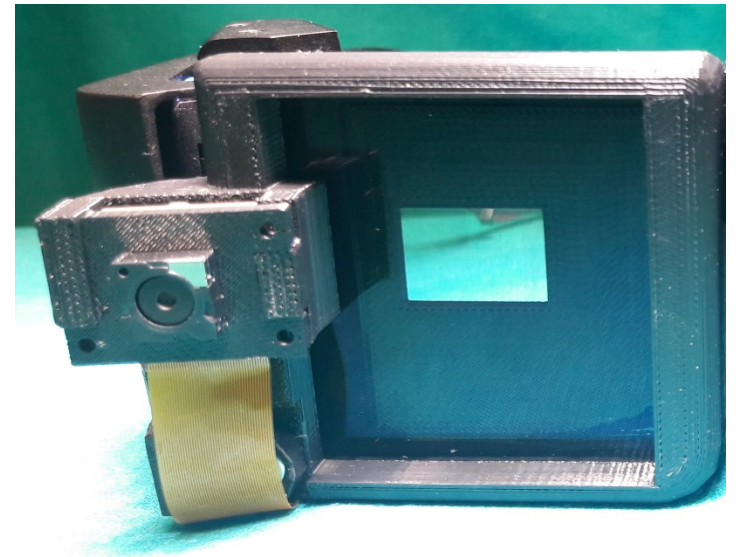
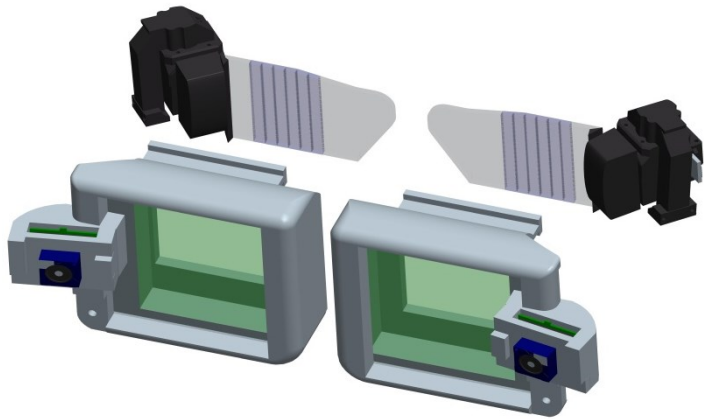
TriVisio SXGA61 3D



Comparison Between OST and VST



OST	VST
Visione naturale del mondo reale.	Visione del mondo reale mediata da camera.
Limite tecnologico nel realizzare display di grandi dimensioni.	Campo di vista aumentato può essere di dimensioni maggiori.
Contenuto virtuale deve essere più luminoso della scena reale per essere visibile.	Pieno controllo della fusione reale-virtuale a livello di pixel.
Le immagini reali sono percepite istantaneamente.	Le immagini reali possono essere ritardate per ridurre il lag relativo R/V.
La trasformazione eye-to-display deve essere stimata (calibrazione user-specific).	Per una corretta registrazione è sufficiente calibrare la camera, non l'occhio!
Interruzione del segnale non significa perdita vista reale.	Interruzione del segnale significa oscurare la vista.



F Cutolo, U Fontana, M Carbone,
R D'Amato, V Ferrari. ISMAR 2017



Real Data source

Virtual Data source

Tracking modality

Registration technique

Visualization Processing

Display type

Perception location



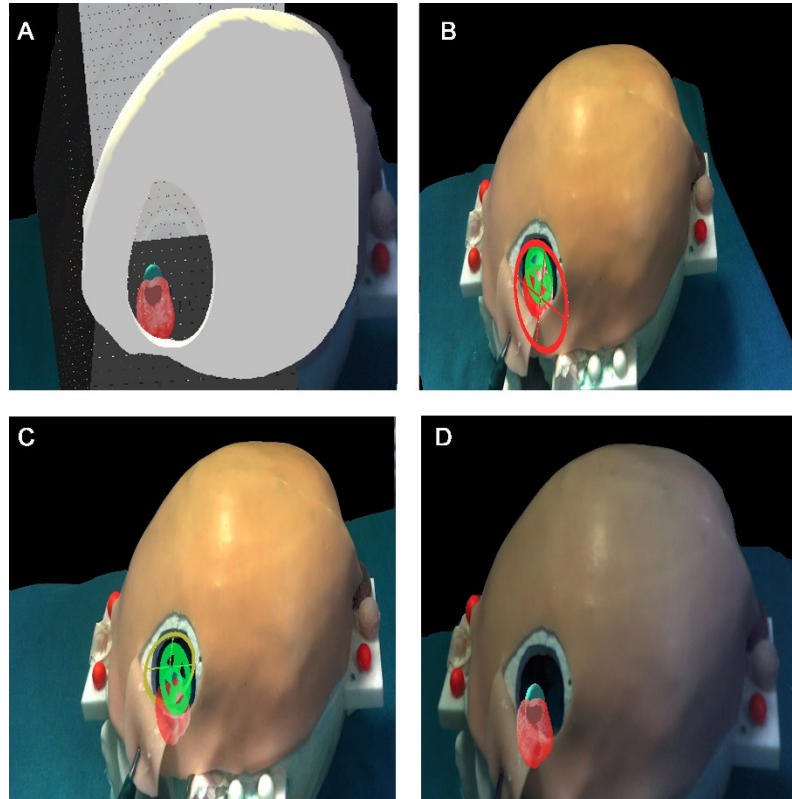
Task-Oriented AR Visualization



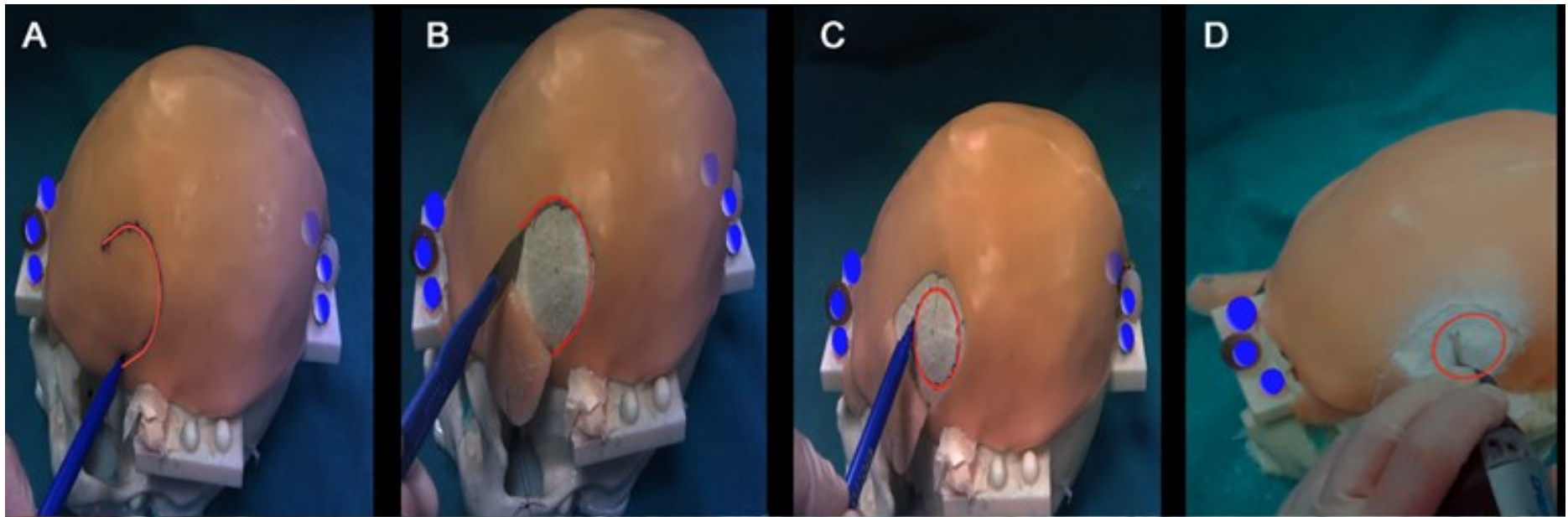
AIM



Allow profitable interaction with the AR guide



Define task-oriented Visualization modalities is preferable than using complex renderings of the virtual content.

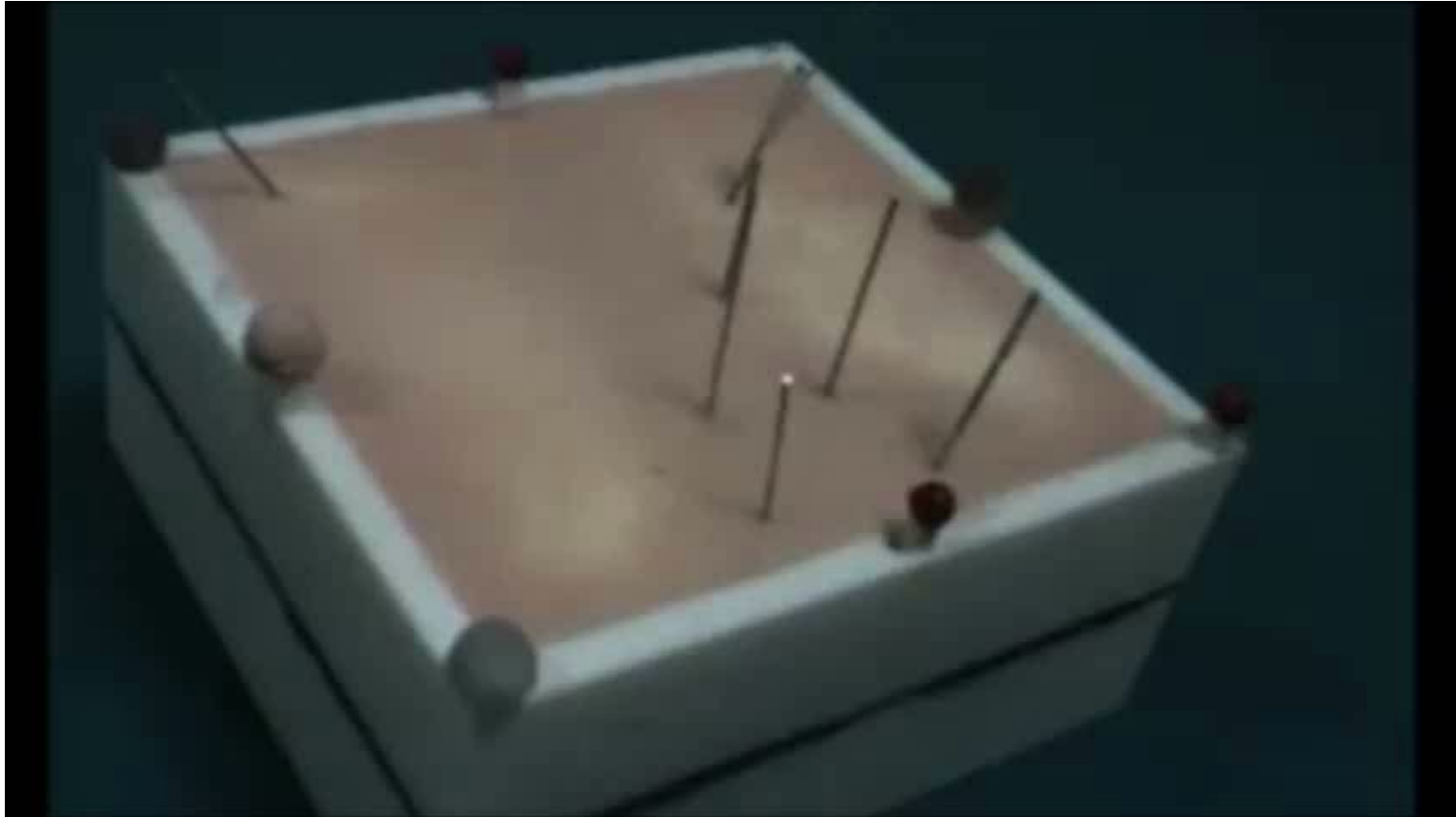




In Vitro Study in Orthopaedic Surgery (2)



Key-Idea: Visualize the planned point of insertion through a **first viewfinder** and the needle trajectory in 3D space through a **second viewfinder**





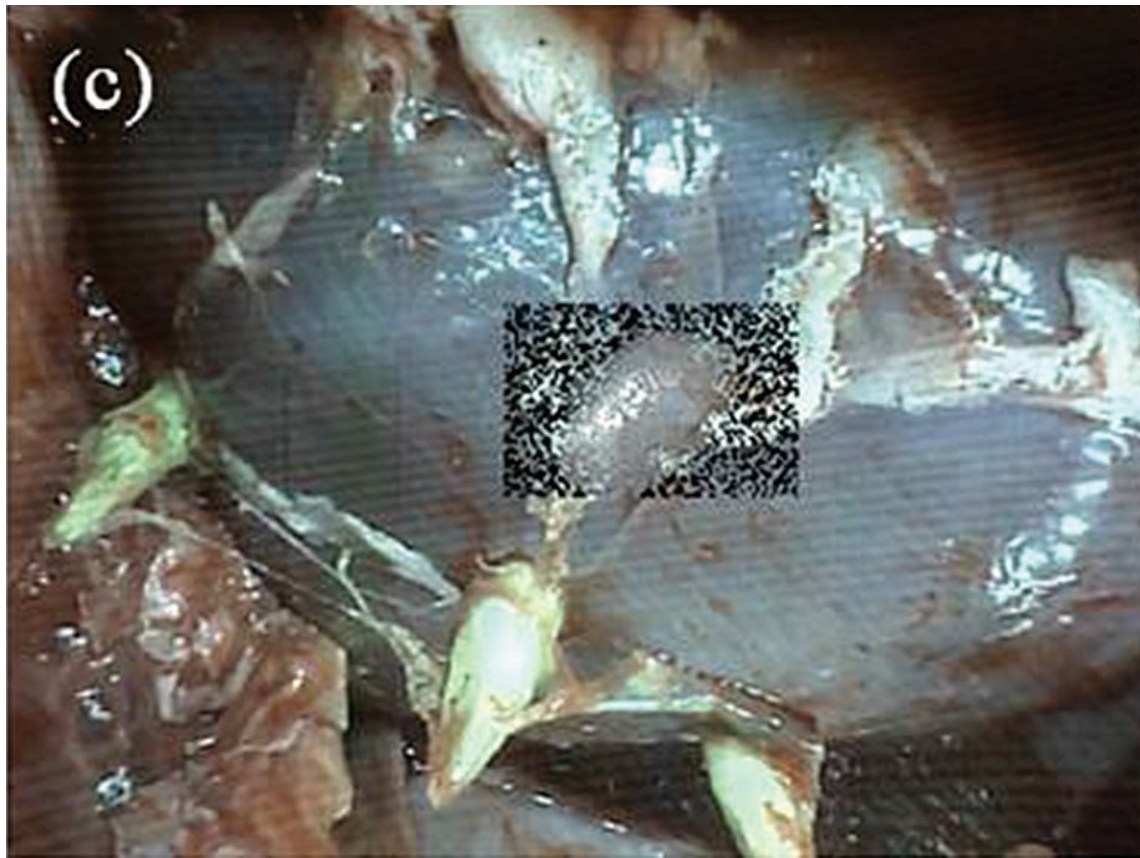
Visualization Techniques for Augmented Reality in Endoscopic Surgery

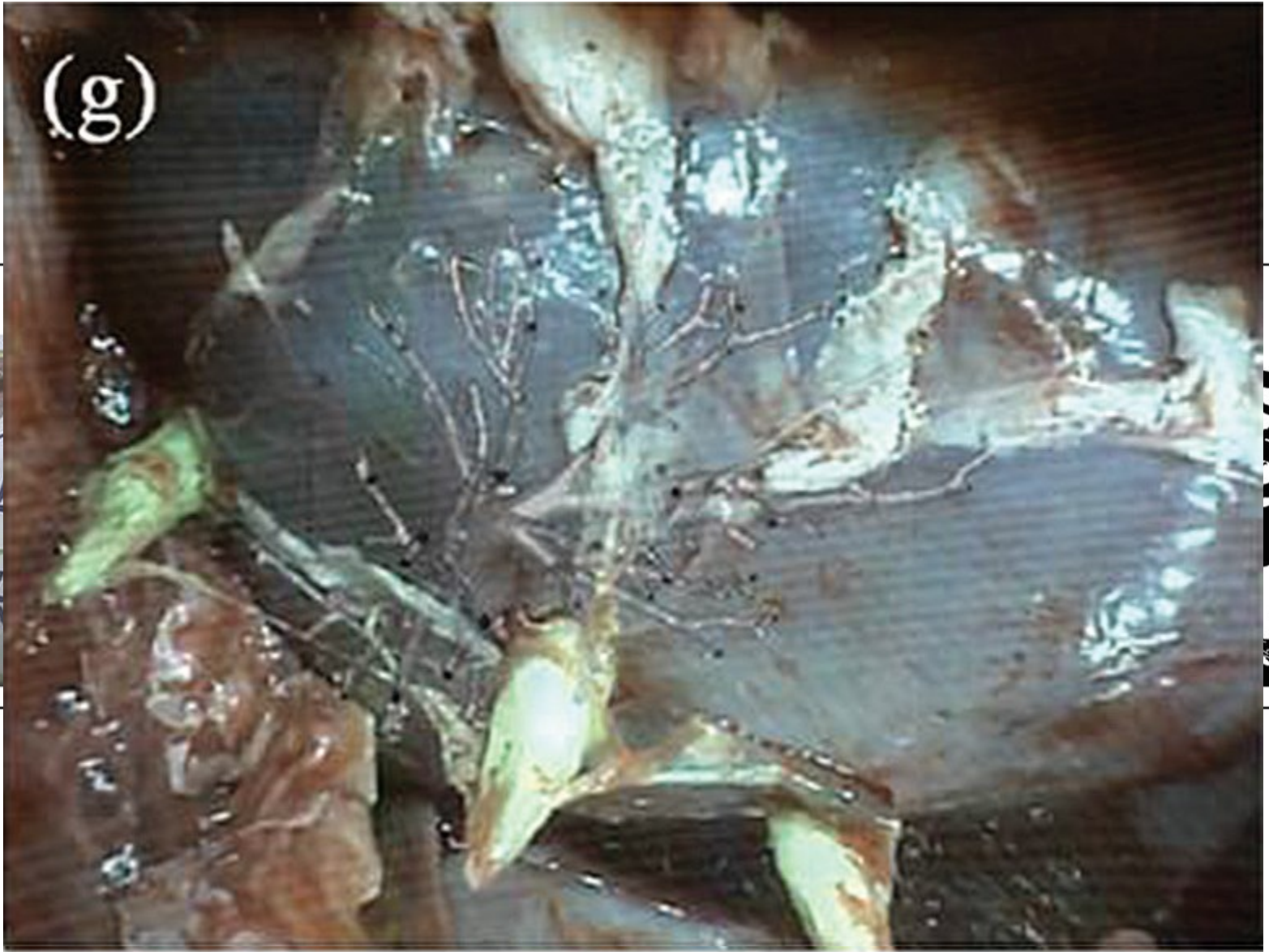
Rong Wang^{1,2}(✉), Zheng Geng¹, Zhaoxing Zhang¹, and Renjing Pei^{1,2}

¹ Institute of Automation, Chinese Academy of Sciences, Beijing, China

wangrong2013@ia.ac.cn

² University of Chinese Academy of Sciences, Beijing, China







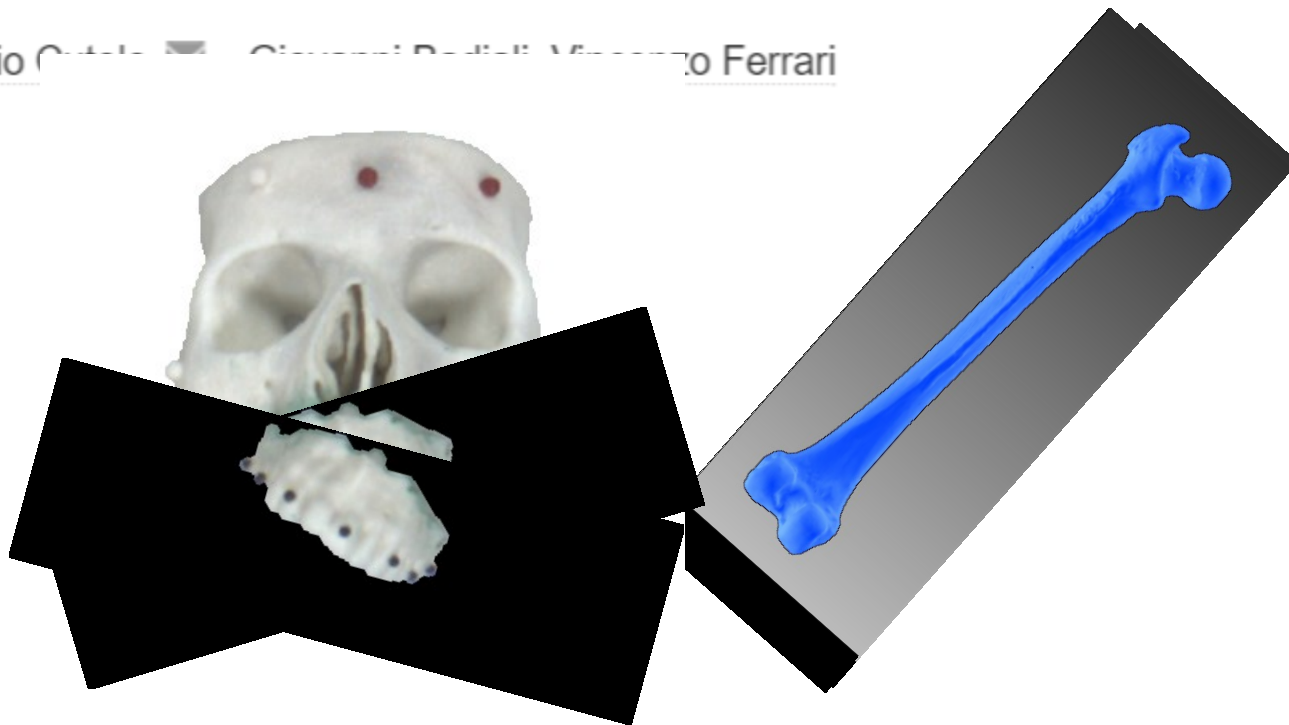
Augmented Environments for Computer-Assisted Interventions

Volume 9365 of the series Lecture Notes in Computer Science pp 50-60

Date: 10 December 2015

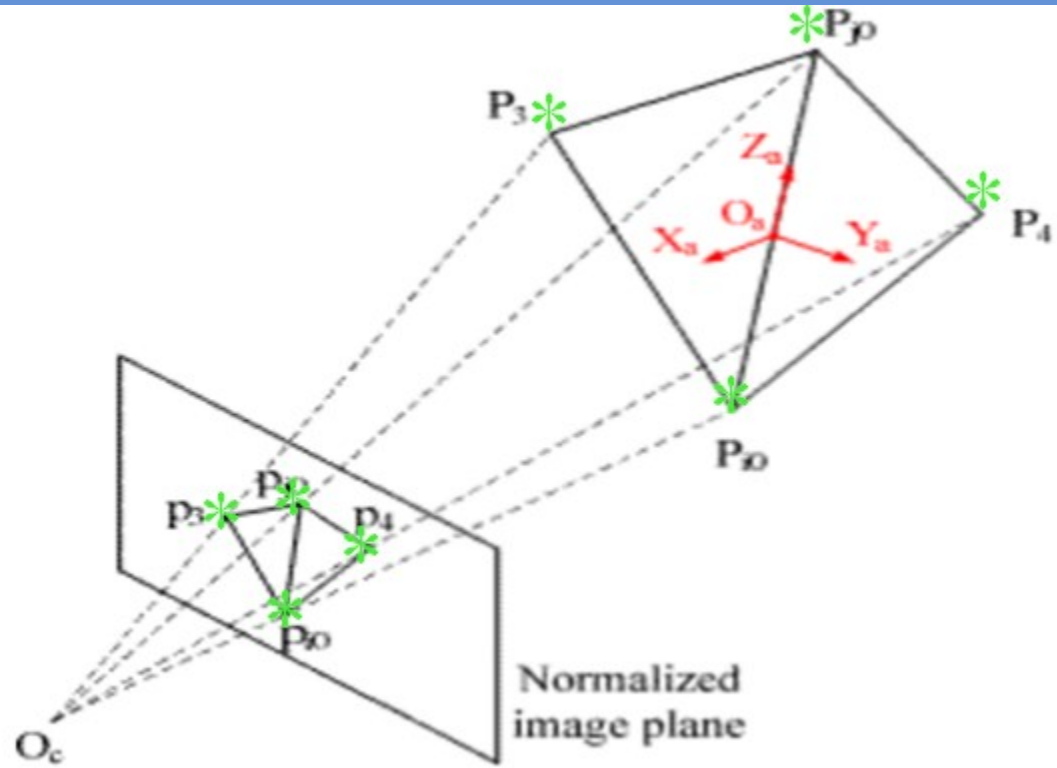
Human-PnP: Ergonomic AR Interaction Paradigm for Manual Placement of Rigid Bodies

Fabrizio Cotta ✉ Cinzia Badiali Massimo Ferrari



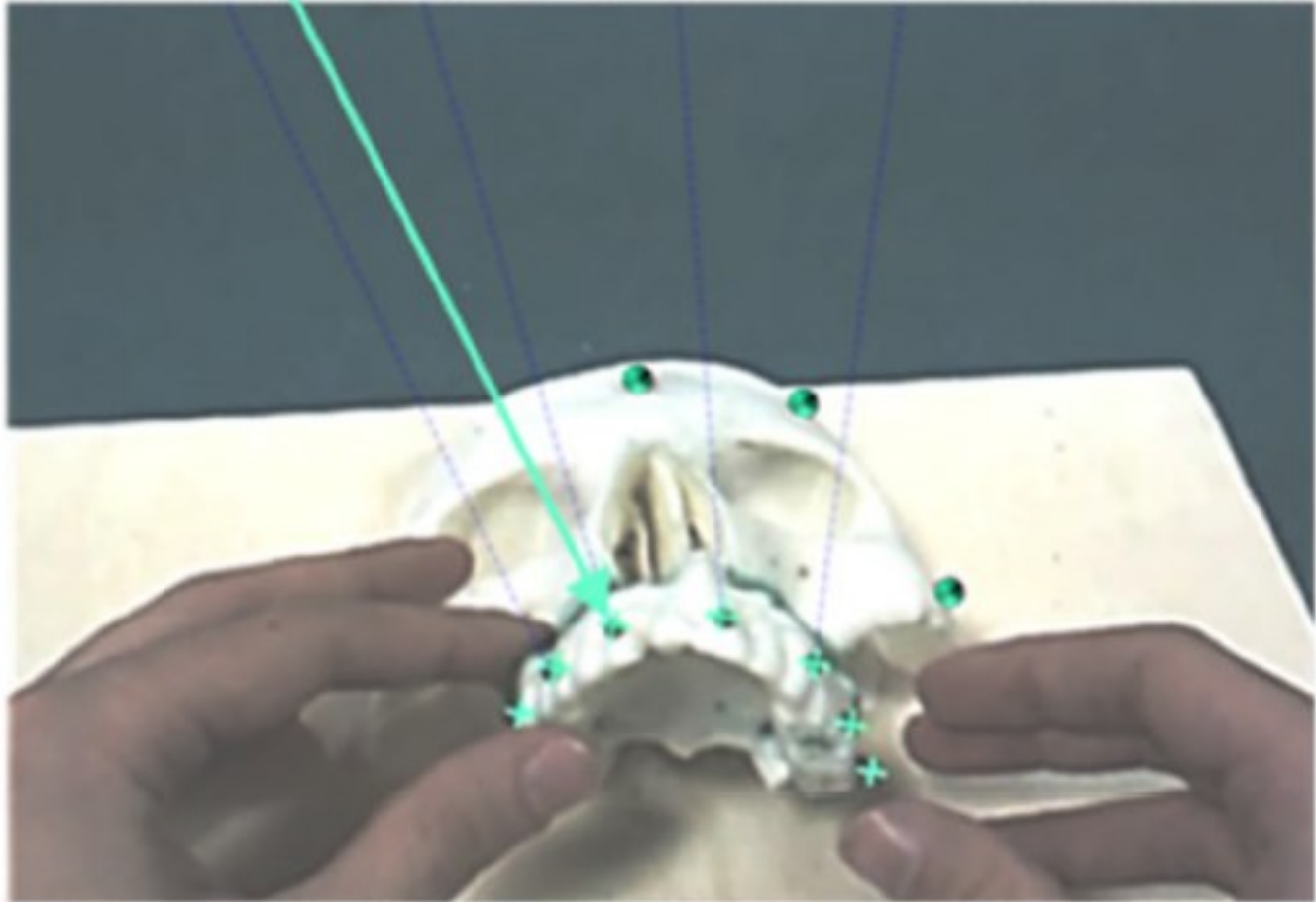


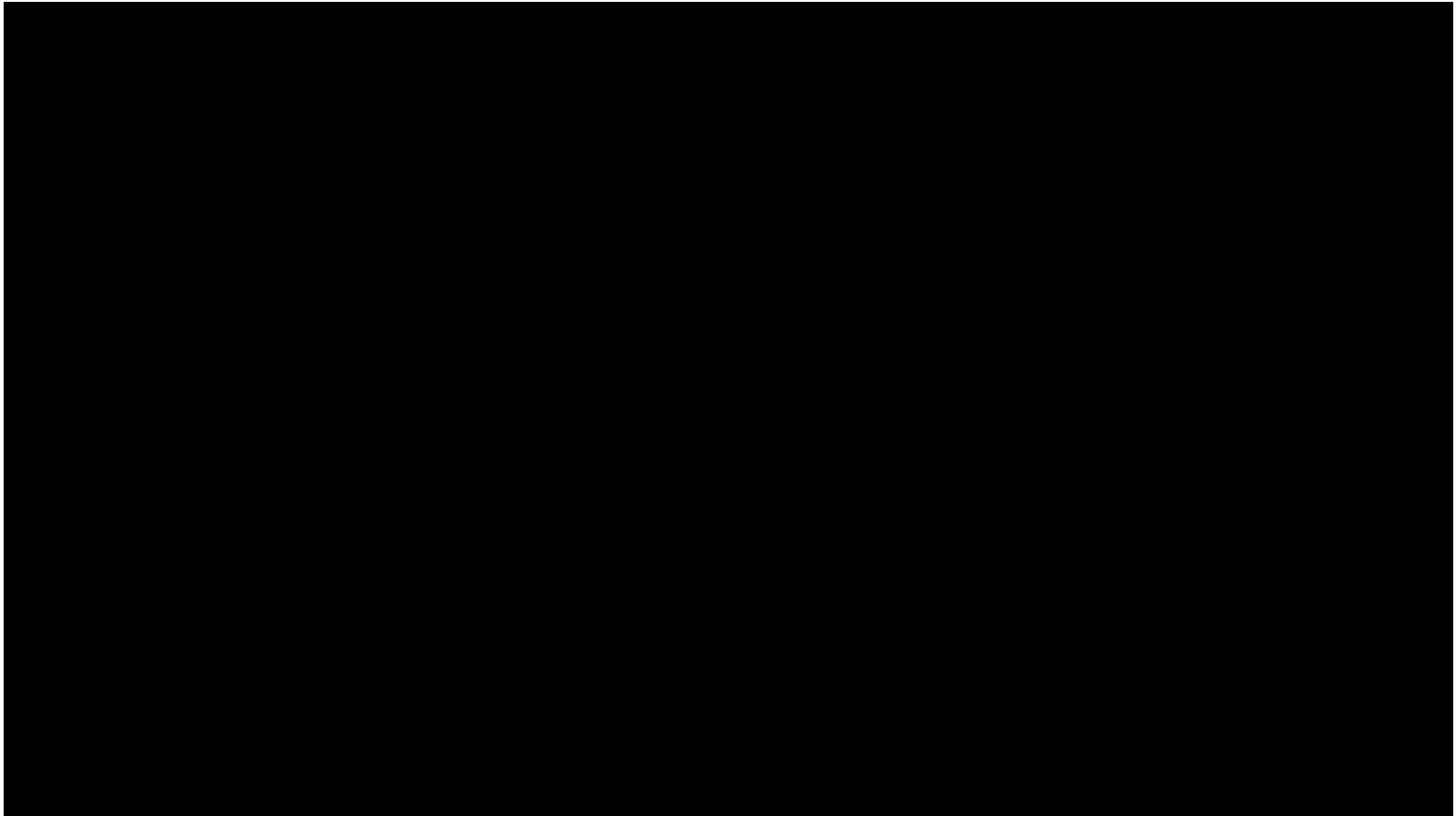
How a robot determines objects pose





$$\bar{p}_i \approx \hat{p}_i$$





Badiali EtAl 2014



Real Data source

Virtual Data source

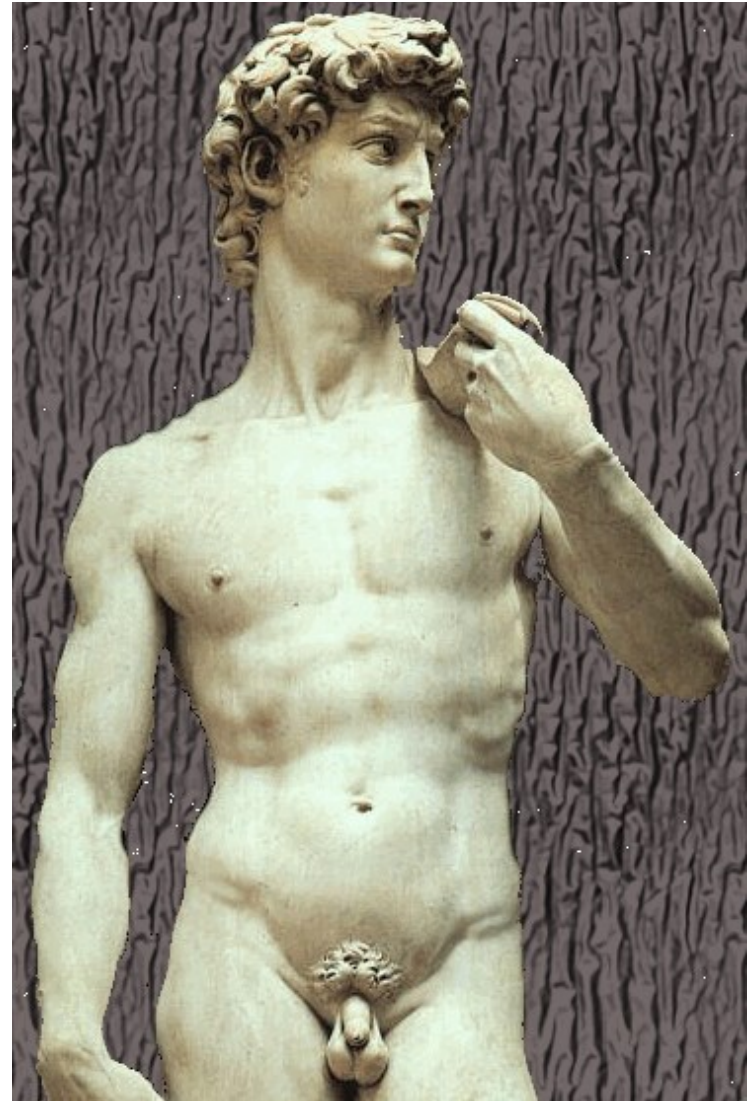
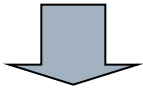
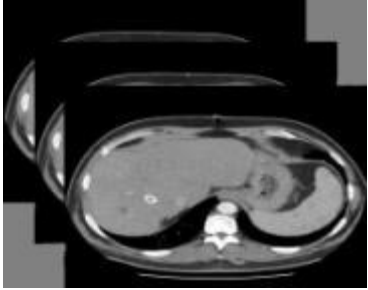
Tracking modality

Registration technique

Visualization Processing

Display type

Perception location





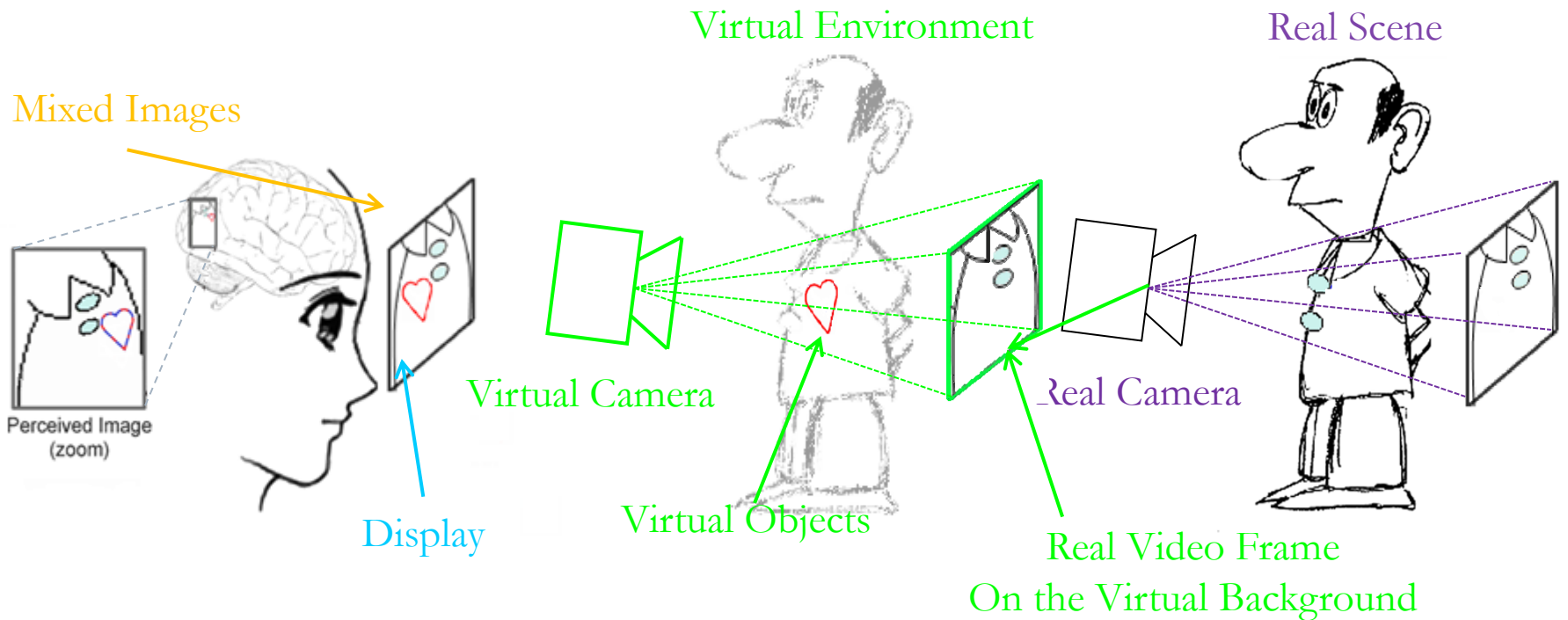
Registration in Video See-Through



<https://www.youtube.com/watch?v=vDNzTasuYEw>



Registration in Video See-Through



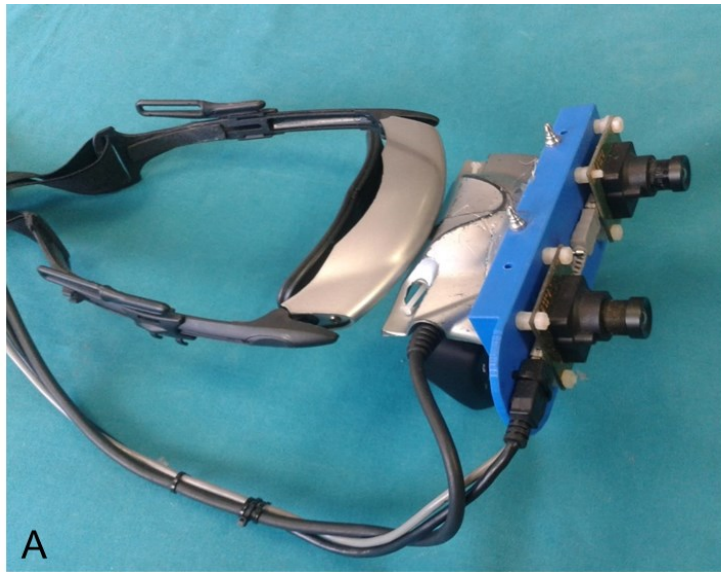
1. Pose of virtual anatomies/virtual surgical tools in respect to the virtual camera \sim real ones (**Tracking & Image to patient Registration.**)
2. Virtual cameras projection models \sim real ones (**Intrinsic Camera calib.**)



EndoCAS Video See-Through AR Visors



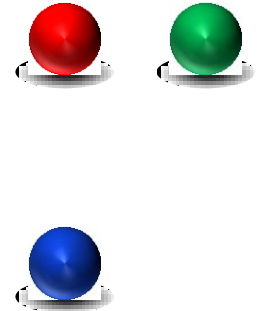
Two external video cameras mounted on commercial 3D visors so to provide a quasi-orthoscopic view of the scene



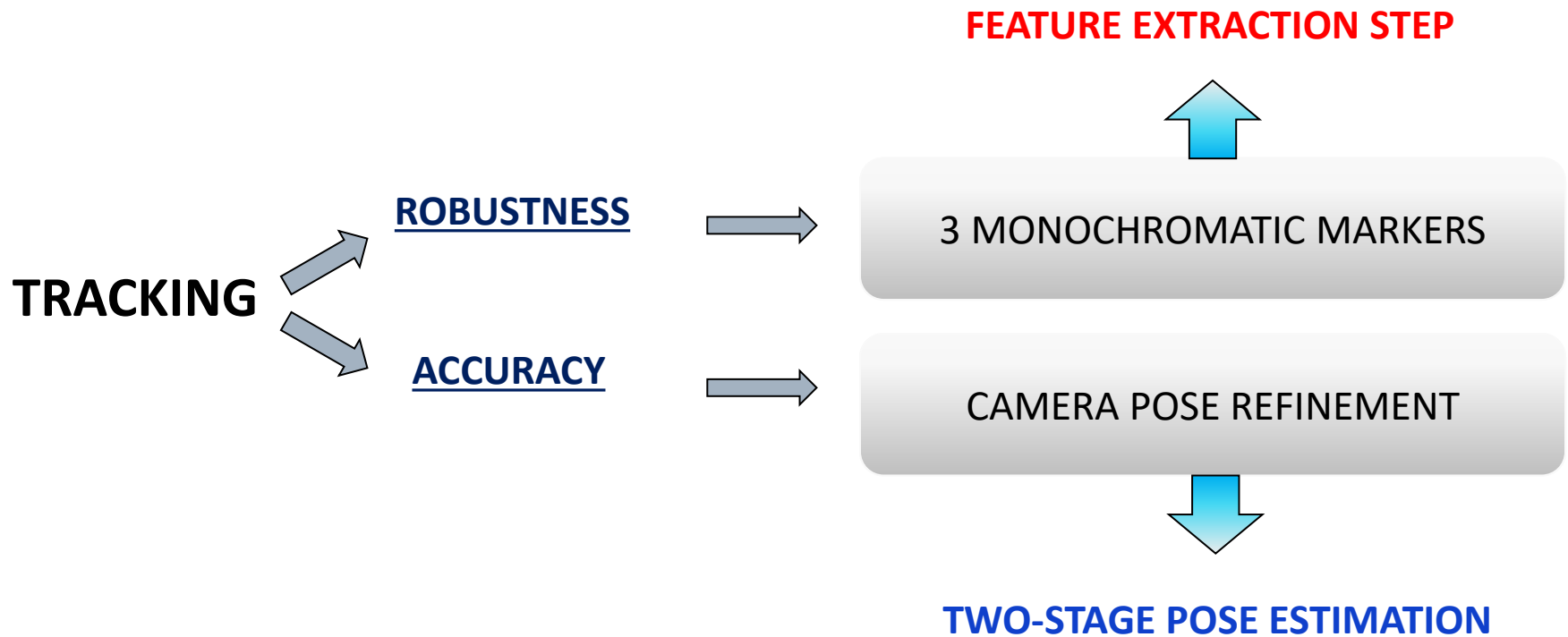
	eMagin Z800 & IDS uEye UI-1646LE	Sony Hmz-T2 & IDS uEye XS
Optimal Resolution	640x512	1280x720 / 640x480
Refresh Rate (fps)	25	15 / 30
Field of View (FoV)	40 deg diagonal	45 deg horizontal



External cameras
form a stereoscopic array



Obiettivo: limitare la complessità tecnica introdotta dai moderni sistemi di navigazione attraverso l'introduzione di metodiche di registrazione video.



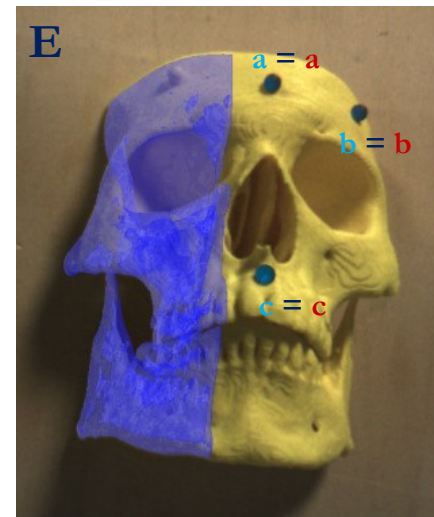


Stereo Tracking Algorithm Step by Step



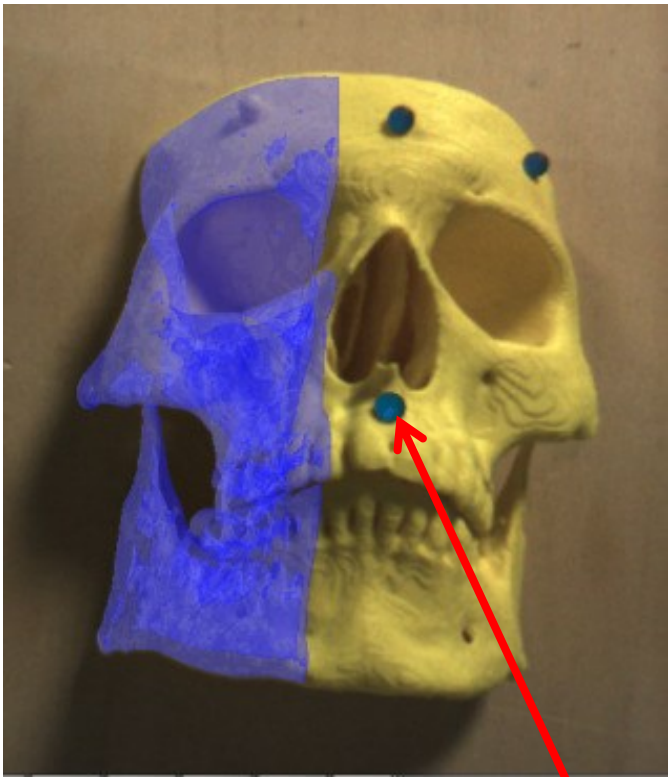
Composed by Machine Vision methods applied on grabbed stereo images:

- A. **Color Segmentation** \implies **HS thresholding (Identify the red-coloured regions)**
- B. **Shape-based Recognition** \implies **Circular-shaped regions are selected** ●
- C. **Markers labelling & 3D Loc.** \implies **Stereo correspondence solved minimizing an energy term among possible matches between triplets.** + + +
- D. **Point Based Registration** \implies **Least Squares Fitting through SVD (initial estimation of the pose) Registrazione rigida con metodo a 3 punti corrisp.**
- E. **Single Camera pose refinement** \implies **Pose Optimization (more accurate)**





Accuracy: Camera Pose Refinement



Due to geometry of the stereo setting, and degradation of the stereo calibration over time, an optimization step in camera estimation is required

	Before Pose Refinement	After Pose Refinement
Left Camera	1.72 pixel (± 0.71)	0.86 pixel (± 0.53)
Right Camera	1.48 pixel (± 0.58)	0.88 pixel (± 0.67)

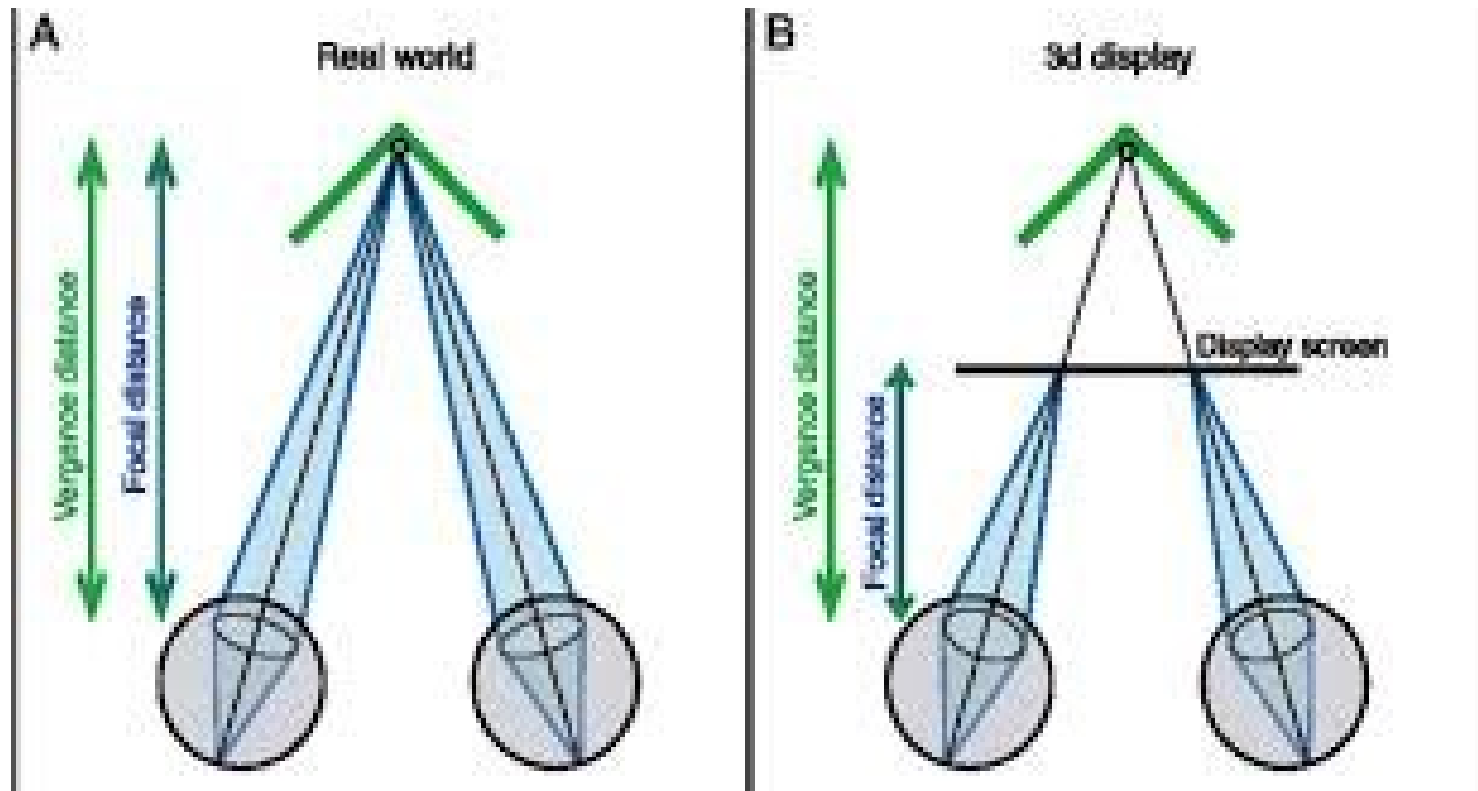
Proposed solution: PnP-based optimization step provides sub-pixel registration accuracy in the image plane



Perceptual Problems on VST Displays



The artificial reproduction of human depth perception in stereoscopic AR IGS is **not** trivial and arises perceptual artifacts (diplopia) that affect the surgeon's interaction with and attitude towards these visualization modalities.

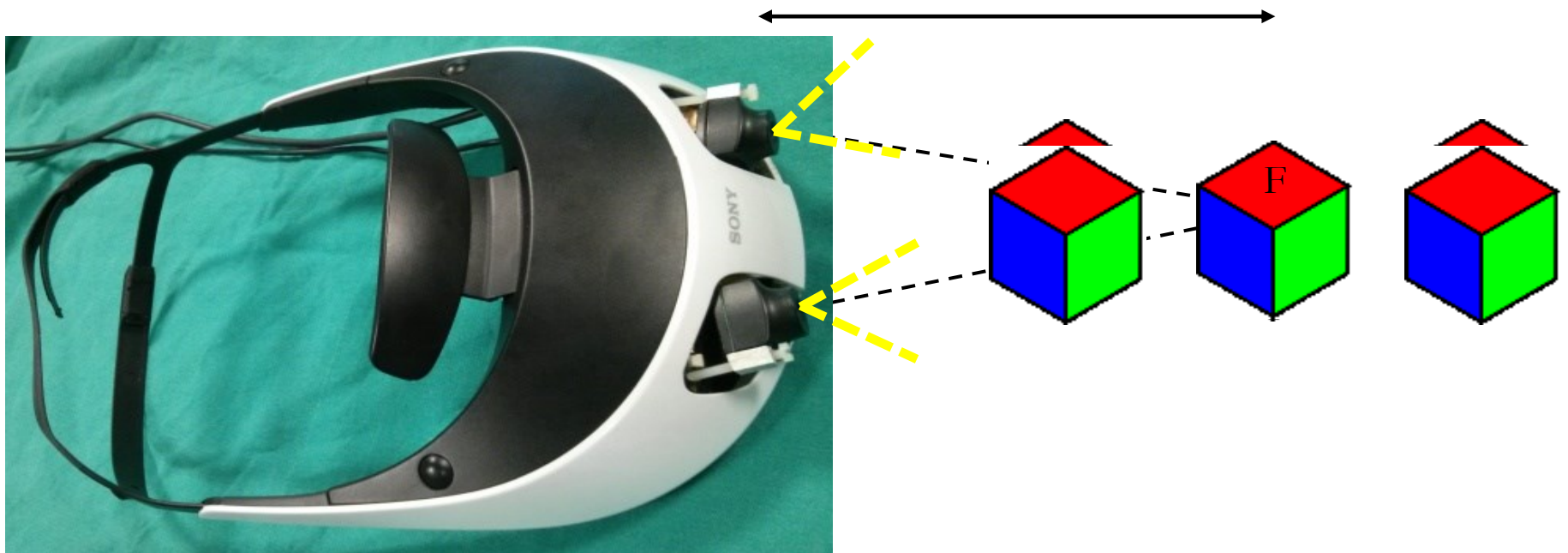




Diplopia in Stereo HMDs



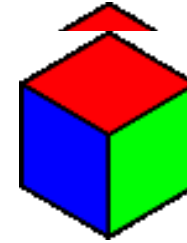
Stereoscopic displays create an illusion of depth perception by providing consistent binocular disparity information in the recorded images delivered to left and right eye.



Sistemi a geometria stereo fissa, generano immagini con ridotte sovrapposizioni stereo e disparità troppo elevate lavorando in zone lontane da quella definite dal fixation point delle due camere.



Matched HW/SW Solution



New HMD with
mechanical adjusters for
vergence control

Adjustable stereo camera vergence in function of the working distances:
stereo overlap is restored and image disparities reduced within fusional area.

Pre-determined calibration data for focus/vergence configurations provide a sufficiently
good initial pose estimation.



C-ARM o Arco a C (Amplificatore di brillantezza mobile)

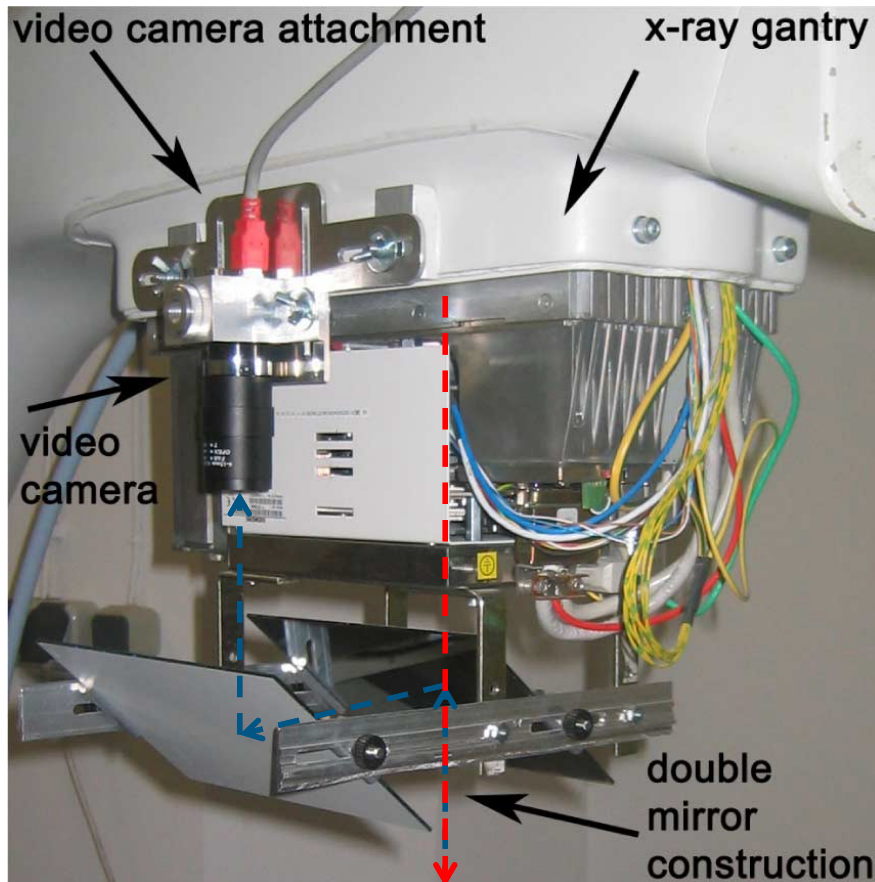
Molto usato in **chirurgia ortopedica, vascolare, d'urgenza**, ed in **chirurgia minimamente invasiva**, ad esso spesso si associano dispositivi di navigazione chirurgica con localizzatori esterni.



Navab et al. [3]:

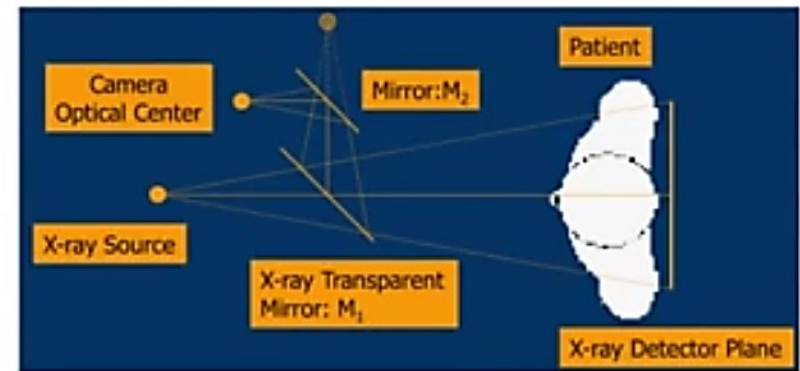
Camera Augmented Mobile C-Arm
(CAMC): Calibration, Accuracy Study,
and Clinical Applications, 2010

Una videocamera ed un sistema a doppio specchio sono integrati in uno standard C-arm mobile



CAMC Configuration

Concept:





Emettitore di Raggi x modellabile come Sistema di proiezione tipo pinhole esattamente come la videocamera esterna. Il montaggio deve avvenire in maniera che l'origine puntiforme dei raggi X (centro della geometria proiettiva dei raggi X) \cong al centro ottico della camera

Per avere corretto allineamento si deve stimare l'omografia $H \in R^{3 \times 3}$ che mappa l'immagine radiologica su quella ottica (= 8 DoF quindi servono almeno 4 punti):

$$\forall \text{ punto } i \quad \lambda \begin{pmatrix} x_c \\ y_c \\ 1 \end{pmatrix} = H \begin{pmatrix} x_{xr} \\ y_{xr} \\ 1 \end{pmatrix}$$

GOAL: Stimare la trasformazione che mappa i punti dello spazio proiettivo della videocamera con quelli dello spazio proiettivo del C-arm: omografia



I passaggi da effettuare prima del calcolo della matrice H sono:

- Stima e compensazione delle distorsioni radiali del C-ARM e della camera ottica.
- Allineamento dei centri di proiezione della camera con origine X-ray. Posizionamento di marker radioopachi su piano superiore della struttura radioopaca di calibrazione, così da coprire, nell'immagine da X-ray, i loro corrispondenti sul piano inferiore.
- Posizionamento della camera rispetto agli specchi in maniera da vedere sovrapposti i marker sui due piani anche nell'immagine ottica.

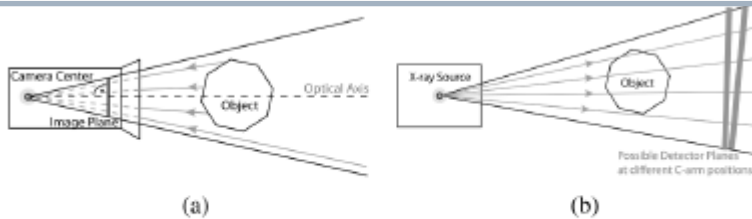


Fig. 3. Basic principles and geometric models of optical camera and X-ray imaging: (a) optical camera and (b) X-ray imaging.

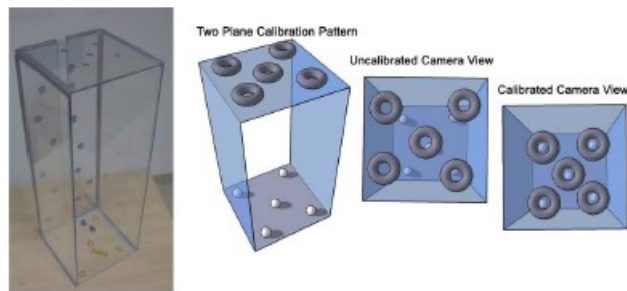


Fig. 6. Bi-planar calibration phantom consists of X-ray and vision opaque markers. On the far plane at the bottom of the calibration phantom five spherical markers are rigidly attached. On the near plane there are five rings attached such that they can be moved and aligned with the spherical markers within the X-ray image.

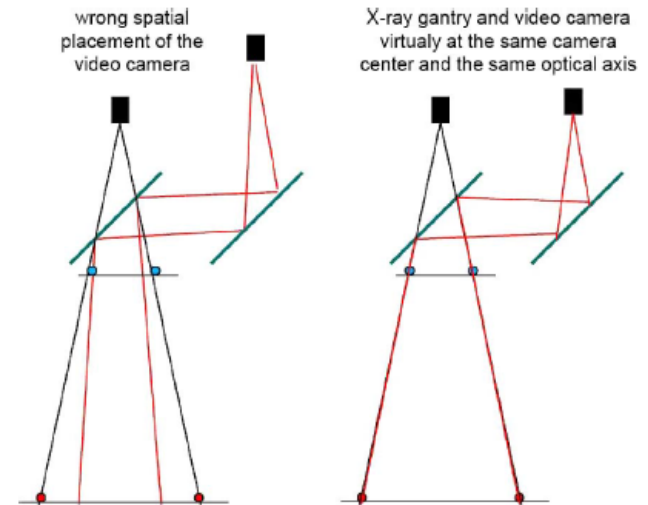


Fig. 4. Video camera has to be attached such that its optical camera center virtually coincides with the X-ray image source.



In questa maniera, con l'omografia $H_{I_{xr} \rightarrow I_c}$, ogni punto sull'immagine radiologica può essere riportato sul punto corrispondente sul piano immagine della videocamera:

$$\mathbf{p}_c (\in I_c) = H_{I_{xr} \rightarrow I_c} \mathbf{p}_{xr} (\in I_{xr})$$

$$\text{N.B. } P_C = K_C [R|0]; P_{xr} = K_{xr} [I|0]; P_C = K_C * R * (K_{xr})^{-1} P_{xr} \leftrightarrow H = K_C * R * (K_{xr})^{-1}$$

- Il sistema è teoricamente registration-free.
- Mette insieme due tipologie di informazioni per aiutare il chirurgo ad orientarsi rispetto all'anatomia con lo strumento chirurgico.
- Particolarmente adatto per la guida «down-the-beam» di strumenti chirurgici (parallela al fascio di X-ray), laddove l'asse dello strumento deve allinearsi alla sorgente di raggi (needle placement, surgical drilling, fissaggio di chiodi endomidollari, procedure percutanee chirurgia vertebrale)

