Augmented Reality(AR): Issues, Trends and Challenges

Invited Speaker : IPTA'2010

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Outline of talk

- Introduction
- Sensors modeling and calibration
- Visual and Hybrid tracking
- AR' Projects
- Conclusions and challenges

Introduction

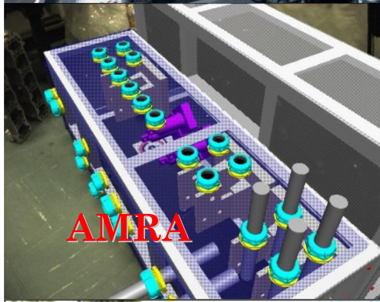
- **Definition :** Augmented Reality (AR) enhances, complete, restore, predict the reality.

- **Objective :** enhance user perception in his real environment. Enhancement could concern all user senses like visual, audio and haptic.

- **Research :** tracking and registration problem is one of the most fundamental challenges, which is still open.

Introduction

- **Augmented Reality:**
  - **Combination of virtual data and real scenes.**
- **Need to ensure visual coherence between two worlds:**
  - **Estimation of the camera pose (position and orientation).**
- **Vision-based methods widely used:**
  - **Still sensitive to outdoor conditions (mobility, change in brightness, occlusion, …).**



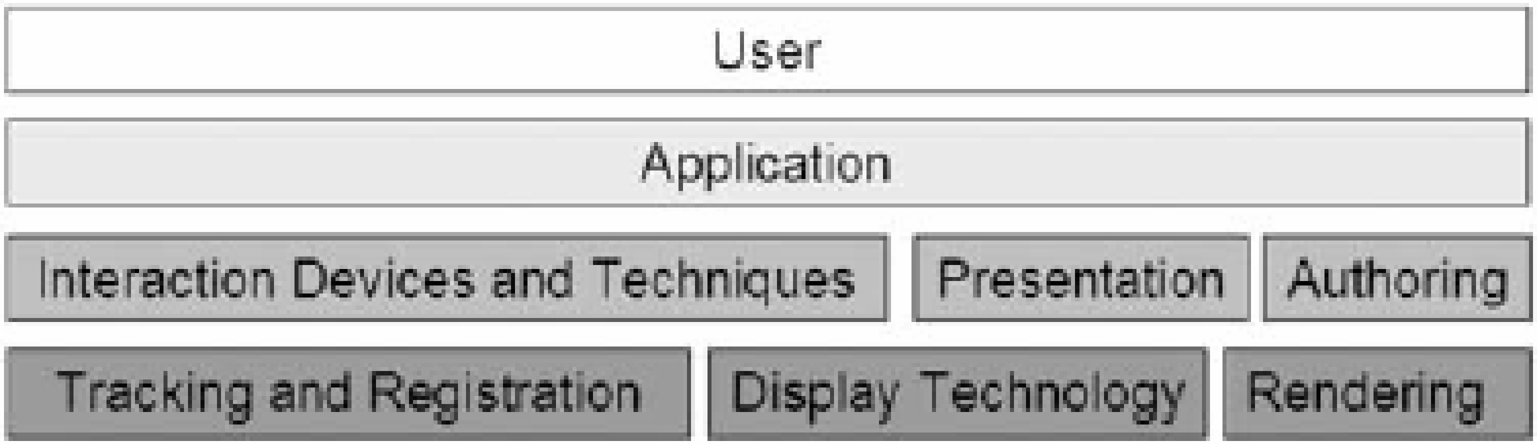
Introduction

Real–Virtual Continuum [Milgram 1994]

- **Fondamental Rules of AR System:**
  - real/virtual Registration
  - real-time Interaction
  - sensorial coherence

Introduction
AR System

AR System allows virtual enhancement of real environment and and real time interaction.



[Bimber2005]

Introduction
AR System

Constraints :

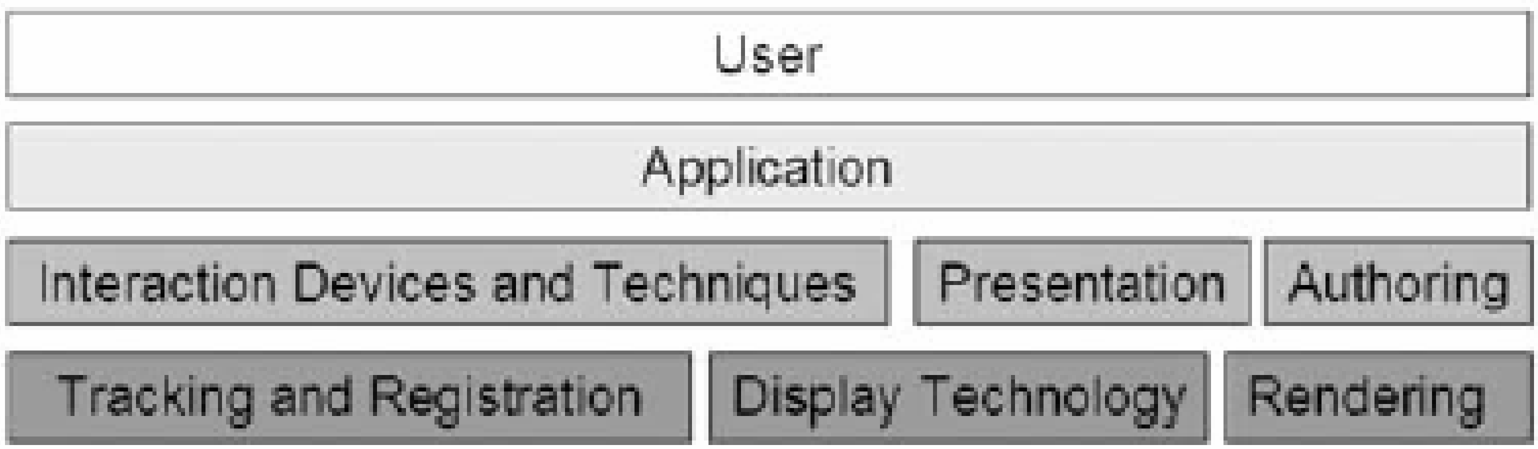
- Augmented Reality System require targets visibility to allow tracking
- The tracking methods may fail under unfavorable conditions of the environment, due to:
  - Presence of important noise
  - Lighting/contrast conditions
  - Occlusion of the target object by an other object

Challenges :

- Localization in real time of the tracking system
- Partial/Total occlusion handling
- Sudden sensors motion
- Elaboration of a multimodal tracking architecture in presence of occlusion for Augmented Reality

Introduction
AR System

AR System allows virtual enhancement of real environment and and real time interaction.

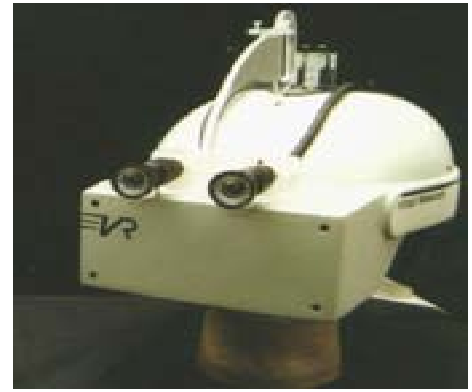


[Bimber2005]

Keywords : Sensors Calibration, 3D modelling, Prediction, 3D registration, Tracking, Rendering, Tangible interface, 3D interaction, Data presentation, Scenario presentation.

Introduction
visualisation devices

Optical see through

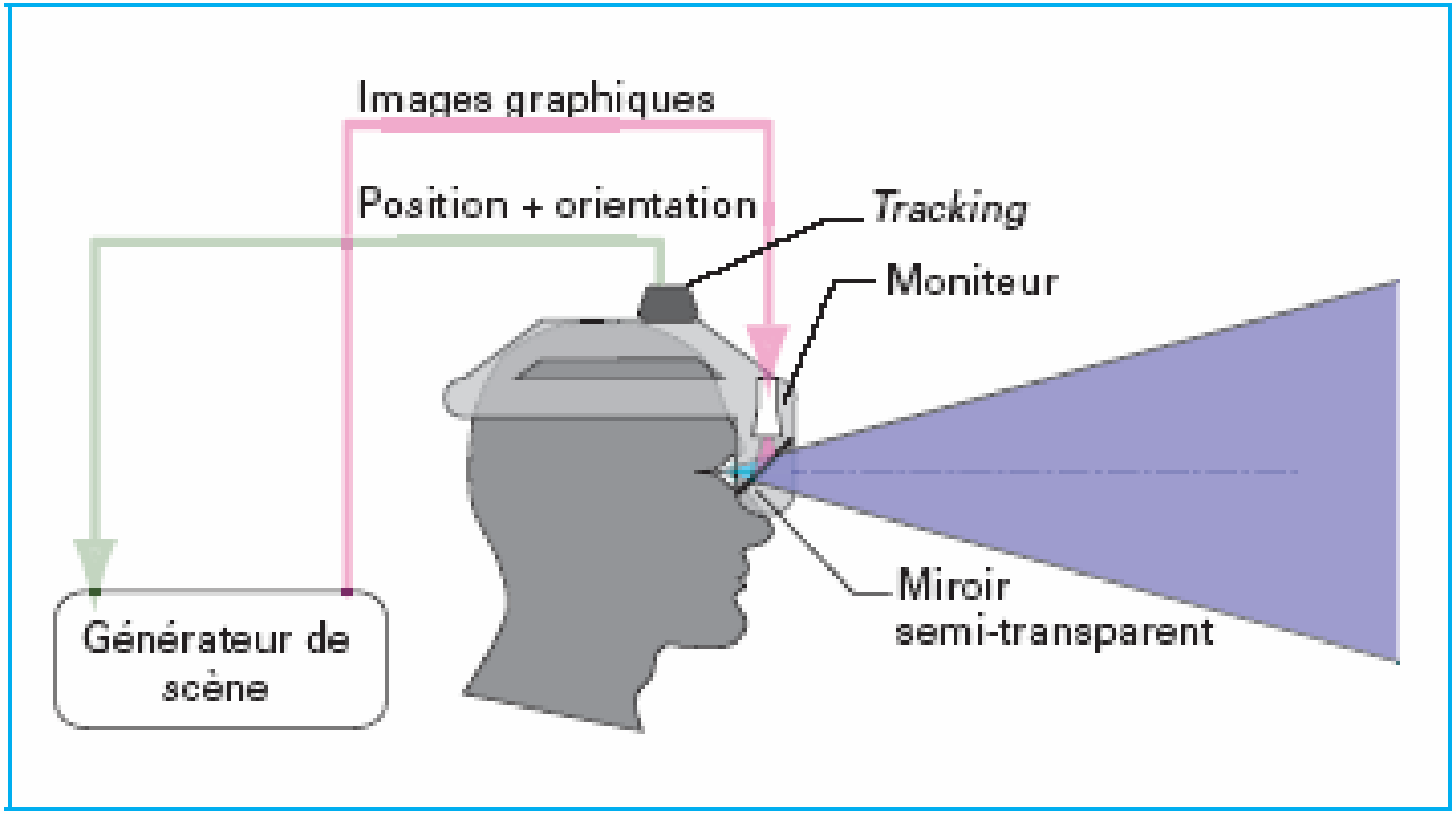


Video see through

3D screen

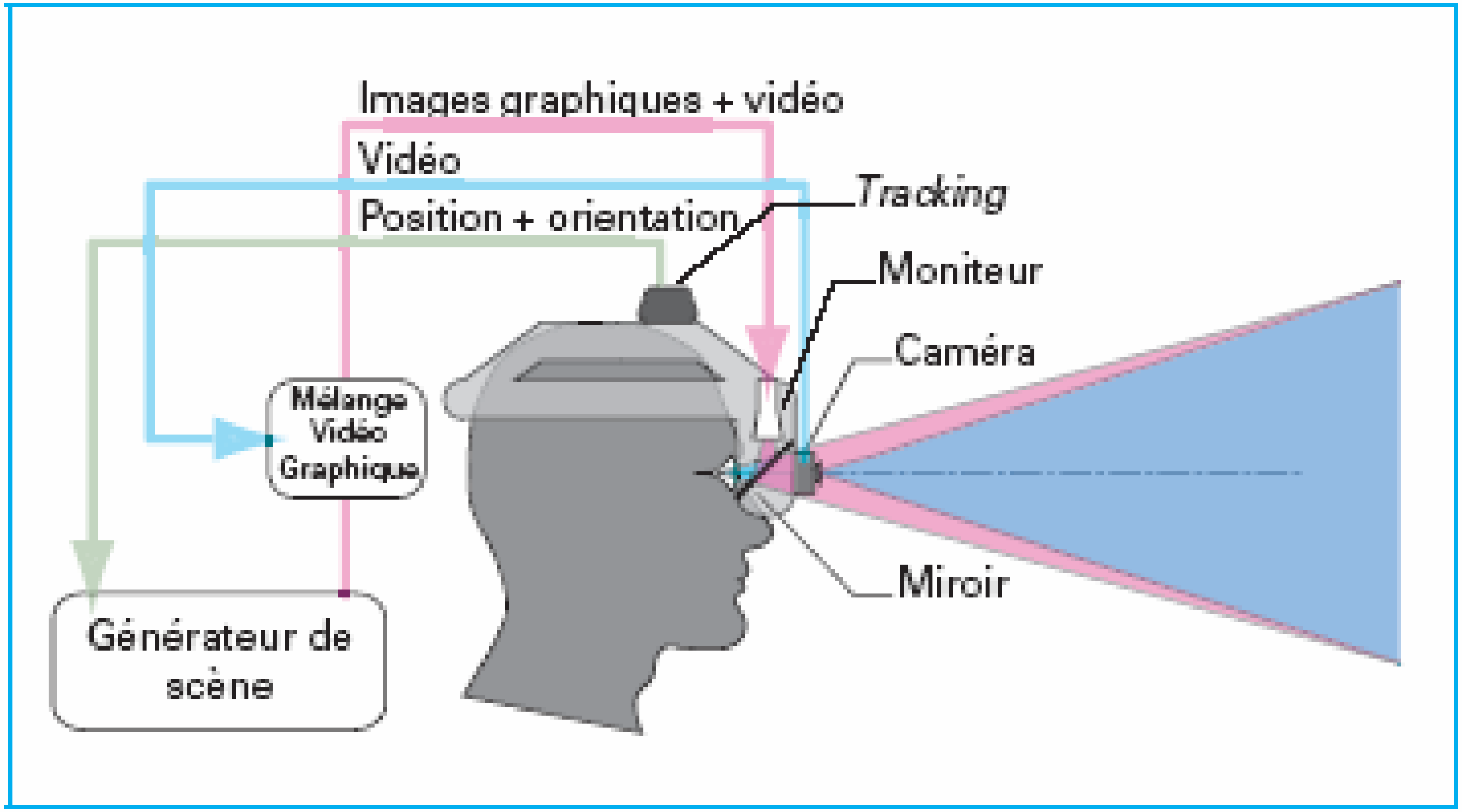
PDA

Introduction
visualisation devices



Head worn device: Optical see-through

Introduction visualisation devices



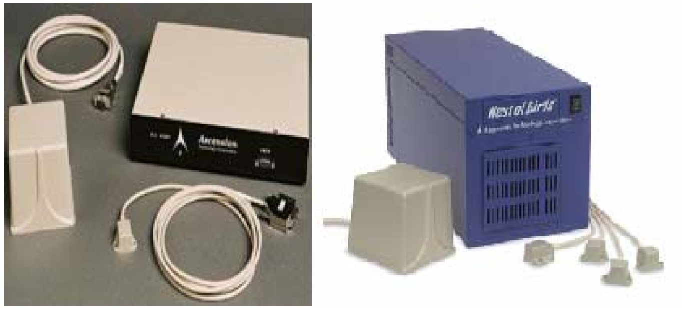
Head worn device: Video see-through

Introduction
Localisation sensors

IMU

US

camera



Magnetic

GPS

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Sensor(s) Modelling and calibration

Sensor (s) = | - 3D sensor → 3D reconstruction
- camera → real/virtual superimposition
- robot → 3D reconstruction, automatic camera calibration

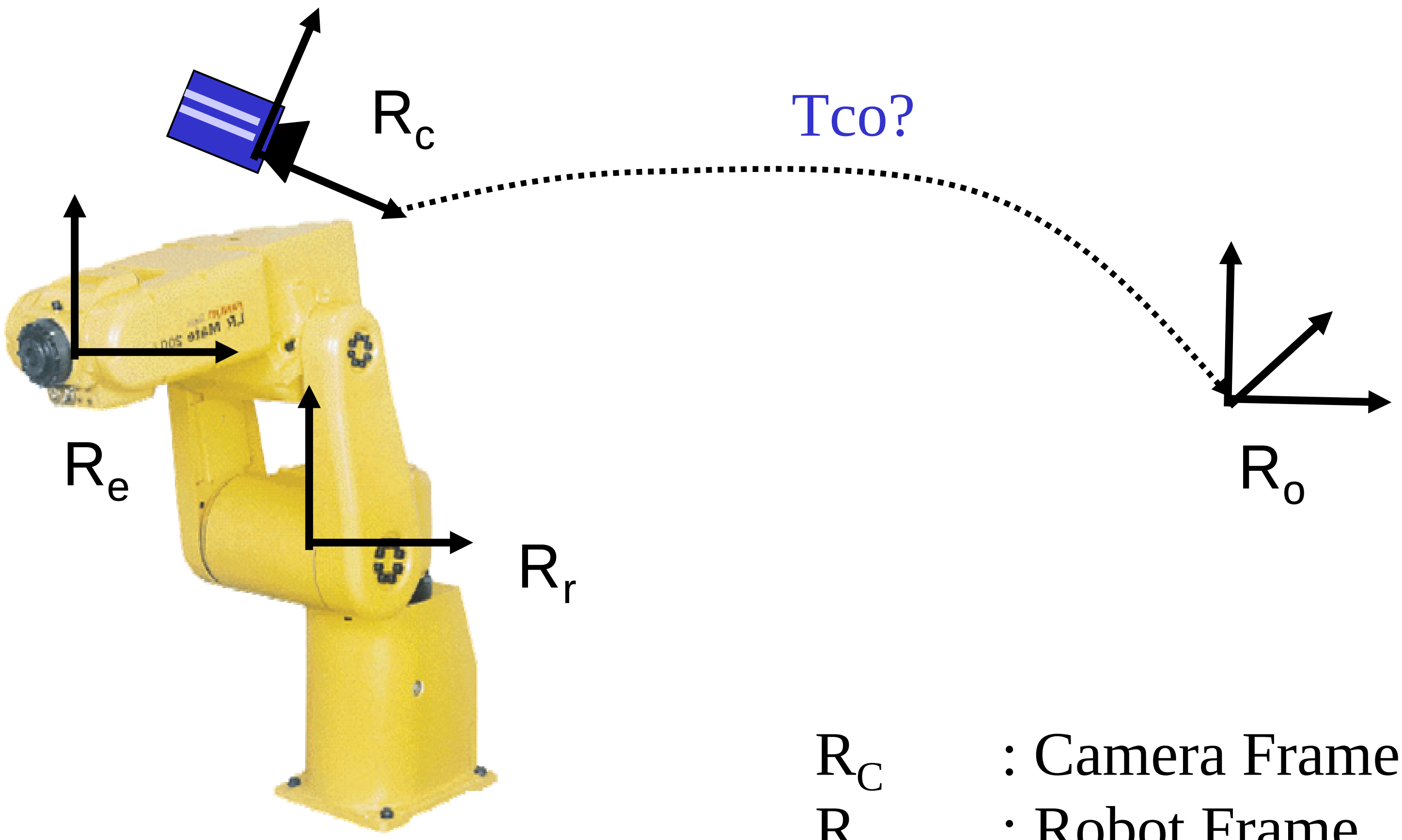
Pre-condition :

Learning Points in different coordinates frames

Post-condition :

Sensor(s) parameters

Example : Camera Modelling and Calibration
Problem Formulation



R_C : Camera Frame

R_r : Robot Frame

Re : End-Effector Frame

R_o : Object Frame

Camera Model

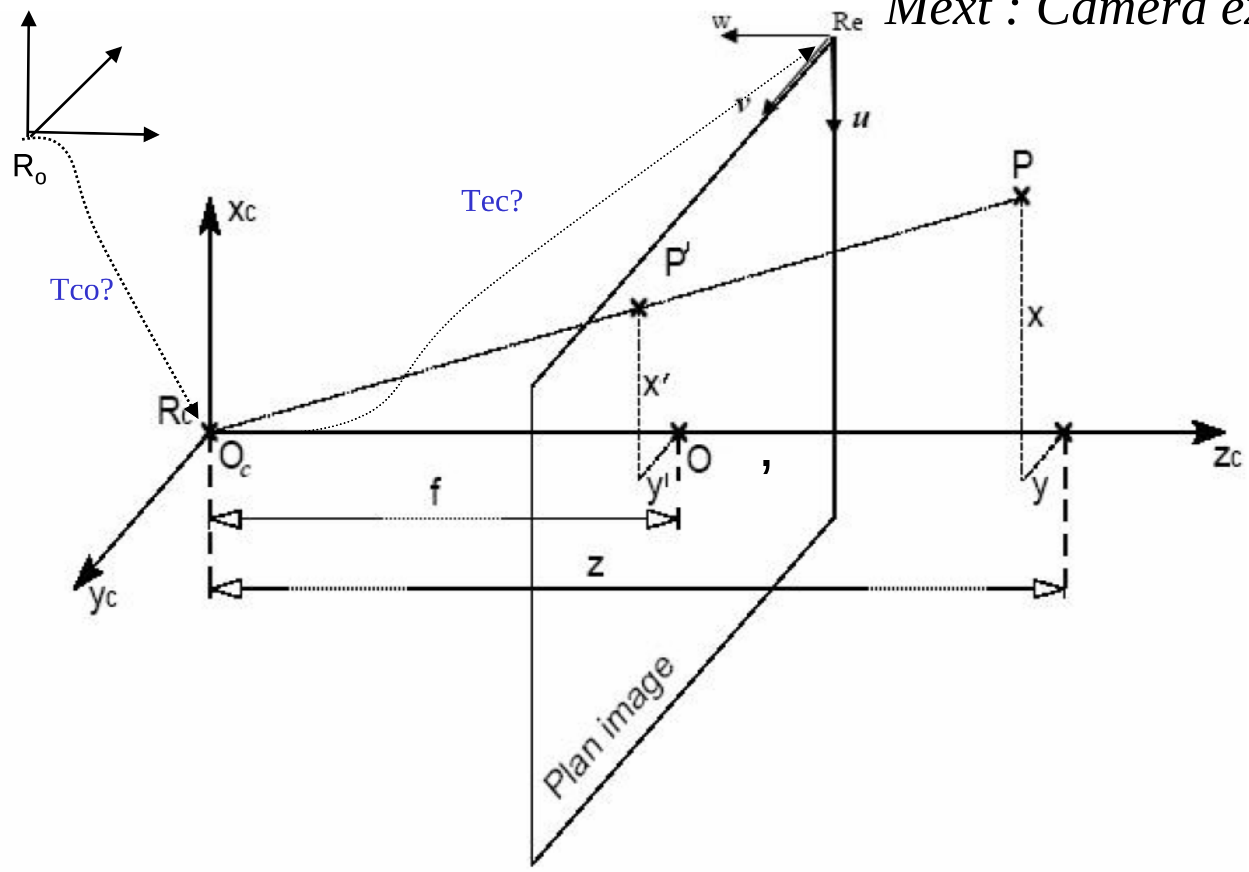
$$p = \underbrace{\overbrace{T_{ec}}^{M\,\mathrm{int}}}\;\underbrace{\overbrace{T_{co}}^{Mext}}\;P \quad (1)$$

p : 2D point,

P : 3D point,

Mint : Camera internal model,

Mext : Camera external model.



Camera Model

$$(1) \Leftrightarrow \begin{bmatrix} su \\ sv \\ s \end{bmatrix} = M\,\mathrm{int}\;\; Mext \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} = M \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

$$\begin{bmatrix} su \\ sv \\ s \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} = \begin{bmatrix} m_1 & m_{14} \\ m_2 & m_{24} \\ m_3 & m_{34} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \Leftrightarrow \begin{cases} u = {P^t m_1 + m_{14}} \big/ {P^t m_3 + m_{34}} \\ v = {P^t m_2 + m_{24}} \big/ {P^t m_3 + m_{34}} \end{cases} \quad (2)$$

$$\Leftrightarrow \begin{cases} P^t.n_u + a_u = 0 \\ P^t.n_v + a_v = 0 \end{cases}, \; avec\; n_u = m_1 - u.m_3 \quad n_v = m_2 - v.m_3 \quad a_u = m_{14} - u.m_{34} \quad a_v = m_{24} - v.m_{34}$$

(2) : Equation of a visual ray including P, p and Oc.

Camera Calibration
mij Estimation

(2) ⇔
$$\begin{cases} u = \dfrac{m_{11}x + m_{12}y + m_{13}z + m_{14}}{m_{31}x + m_{32}y + m_{33}z + m_{34}} \\ v = \dfrac{m_{21}x + m_{22}y + m_{23}z + m_{24}}{m_{31}x + m_{32}y + m_{33}z + m_{34}} \end{cases} \qquad (3)$$

• ***6 non coplanar points at least are used.***

(3) ⇔
$$\begin{aligned} m_{11}x_i + m_{12}y_i + m_{13}z_i + m_{14} - u_i m_{31}x_i - u_i m_{32}y_i - u_i m_{33}z_i = u_i m_{34} \\ m_{21}x_i + m_{22}y_i + m_{23}z_i + m_{24} - v_i m_{31}x_i - v_i m_{32}y_i - v_i m_{33}z_i = v_i m_{34} \end{aligned} \qquad (4)$$

• ***Least square method is applied to estimate mij.***

Calibration de caméra

mij Estimation

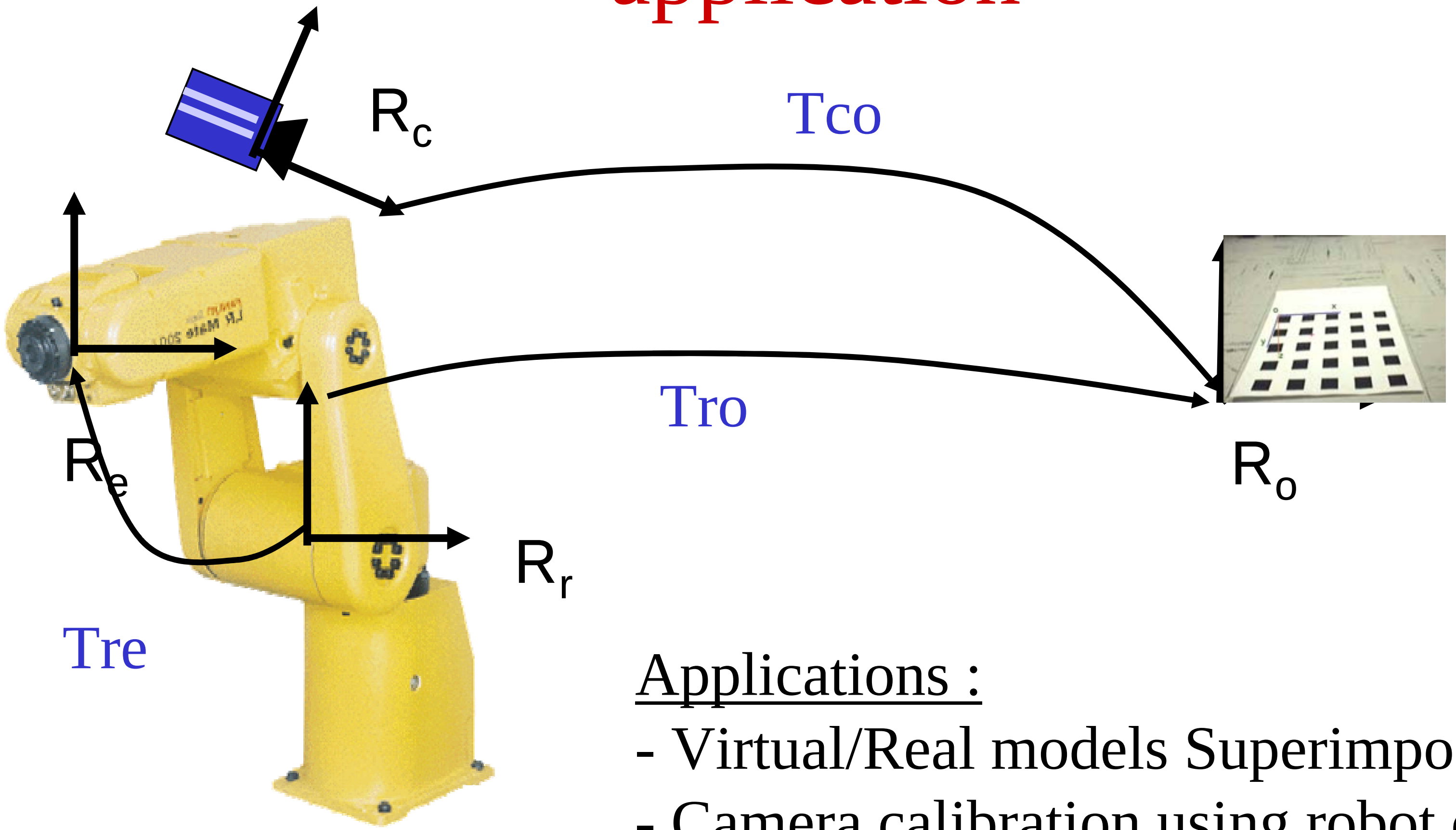
•2N équations for N known points, are expressed as :

$$\begin{bmatrix} & & & & & & \vdots & & & & \\ x_i & y_i & z_i & 1 & 0 & 0 & 0 & 0 & -u_i x_i & -u_i y_i & -u_i z_i \\ 0 & 0 & 0 & 0 & x_i & y_i & z_i & 1 & -v_i x_i & -v_i y_i & -v_i z_i \\ & & & & & & \vdots & & & & \end{bmatrix} \begin{bmatrix} m_{11} \\ m_{12} \\ m_{13} \\ m_{14} \\ m_{21} \\ m_{22} \\ m_{23} \\ m_{24} \\ m_{31} \\ m_{32} \\ m_{33} \end{bmatrix} = \begin{bmatrix} \vdots \\ u_i m_{34} \\ v_i m_{34} \\ \vdots \end{bmatrix} \qquad (5)$$

•(5) represents a linear system : $H.m = p$

•Estimation of mij is obtained as follows : $m = (H^t.H)^{-1}.H^t.p$ (6)

Camera calibration : application



Applications :

- Virtual/Real models Superimposition,
- Camera calibration using robot data.

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Tracking

Objective: virtual ans real worlds coherence

Pre-conditions :

-Sensor(s) modelling and calibration,

-Target(marker) image processing,

-Partial virtual model of the environment known.

Post-condition :

Pose sensor(s) updating

Tracking
Problem Formulation

$$F(p, P, M_{int}, R, T) = 0$$

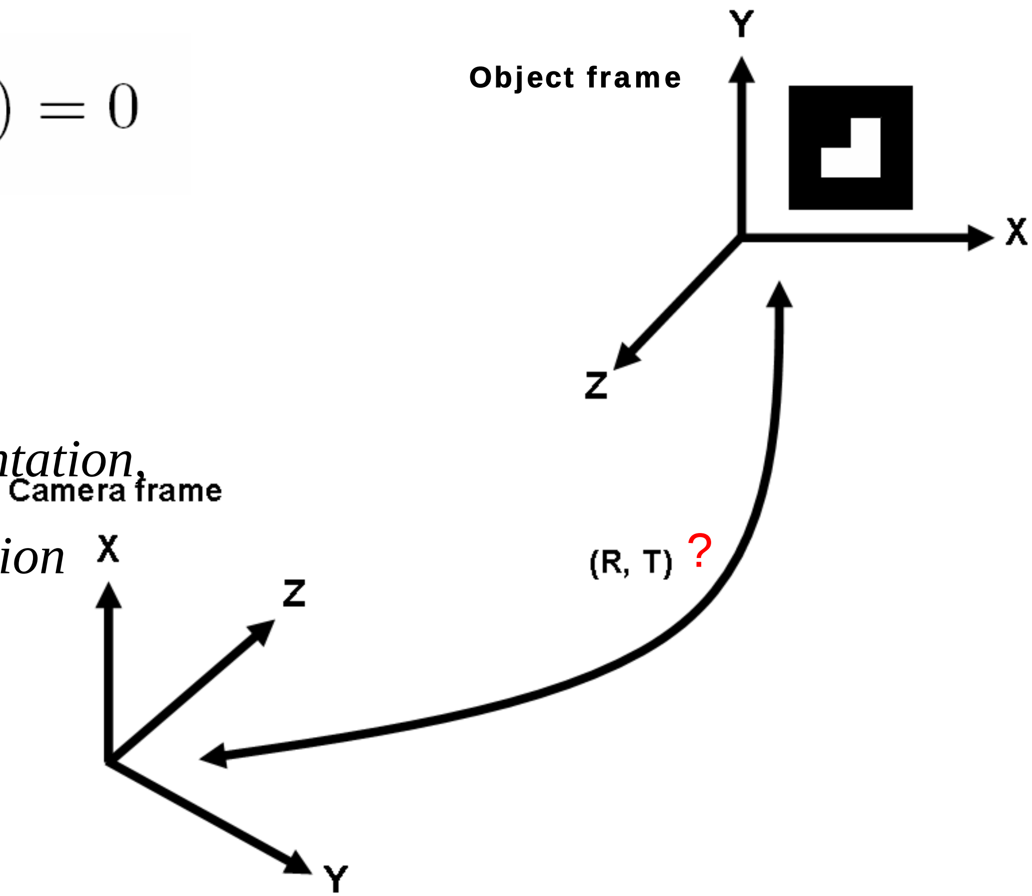
p : 2D point,

P : 3D point,

Mint : Camera model,

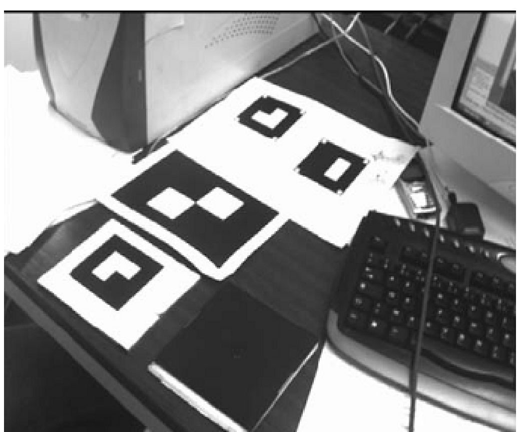
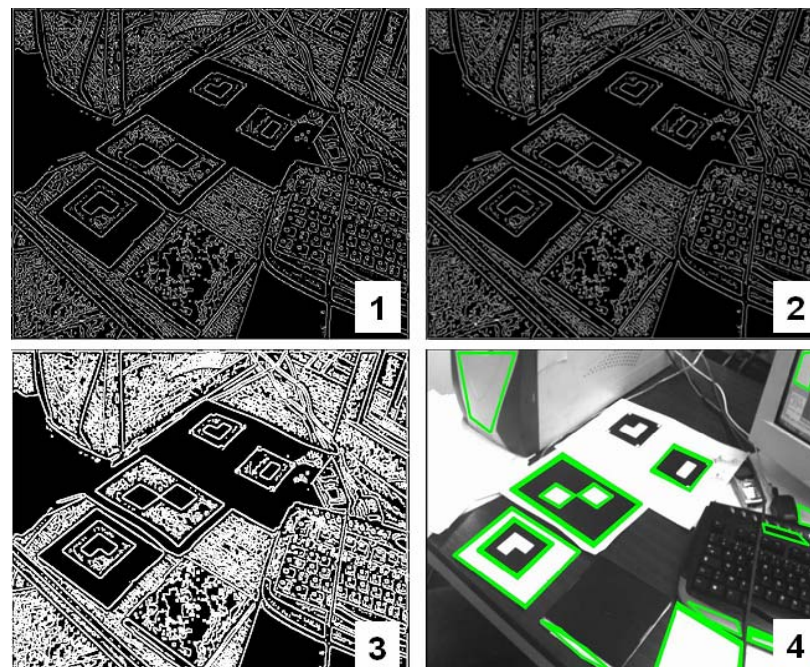
R : Camera/Object orientation,

T : Camera/Object position

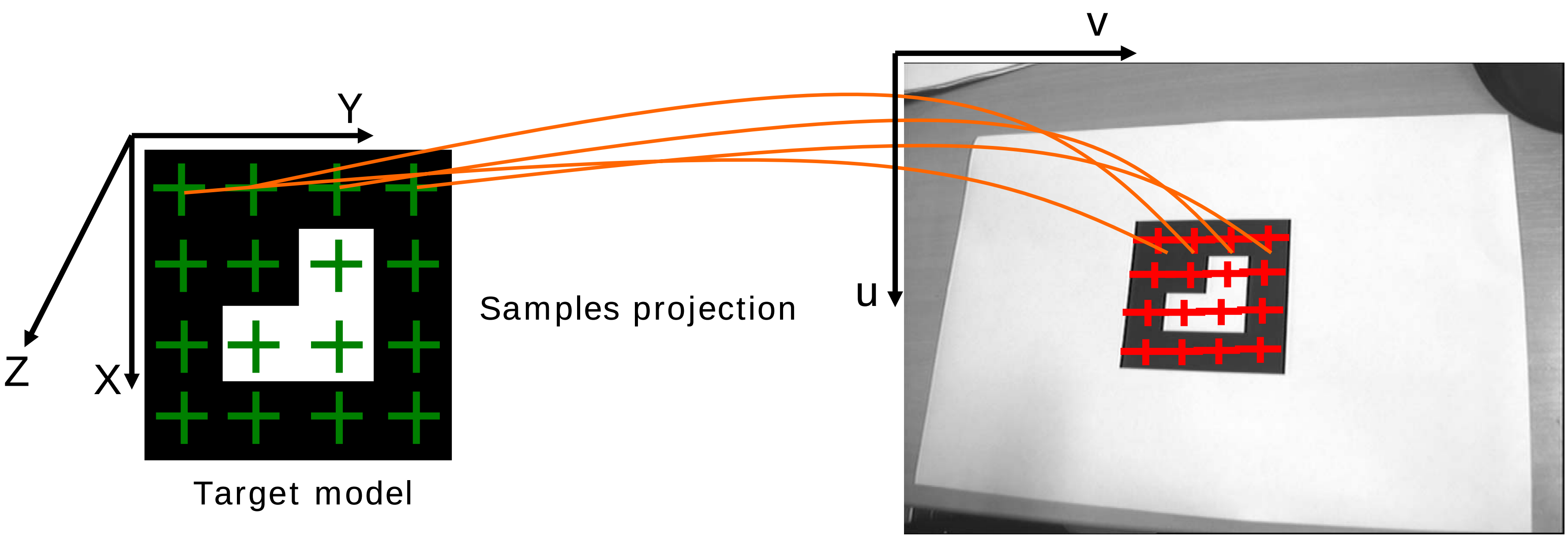


Vision based Tracking
Image processing

1. Contours detection
2. Image smoothing
3. Image dilatation
4. Polygonal approximation of contour
5. Computation of minimal angles between edges

Vision based Tracking
Target Identification

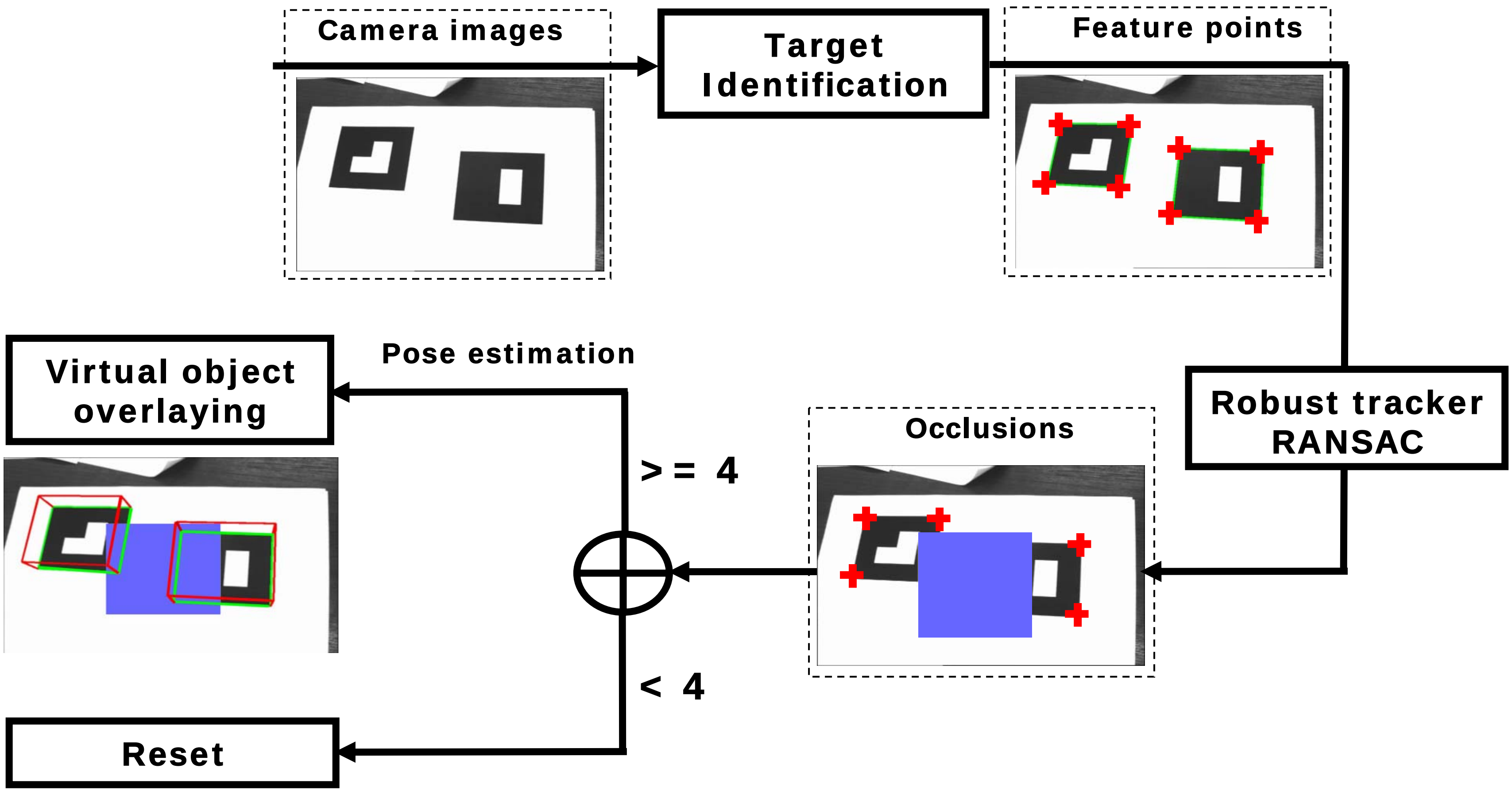


$$\begin{pmatrix} x & y & 1 & 0 & 0 & 0 & -xu & -yu \\ 0 & 0 & 0 & x & y & 1 & -xv & -yv \end{pmatrix} \begin{pmatrix} h_{11} \\ h_{12} \\ h_{13} \\ h_{21} \\ h_{22} \\ h_{23} \\ h_{31} \\ h_{32} \end{pmatrix} = \begin{pmatrix} h_{33}u \\ h_{33}v \end{pmatrix}$$

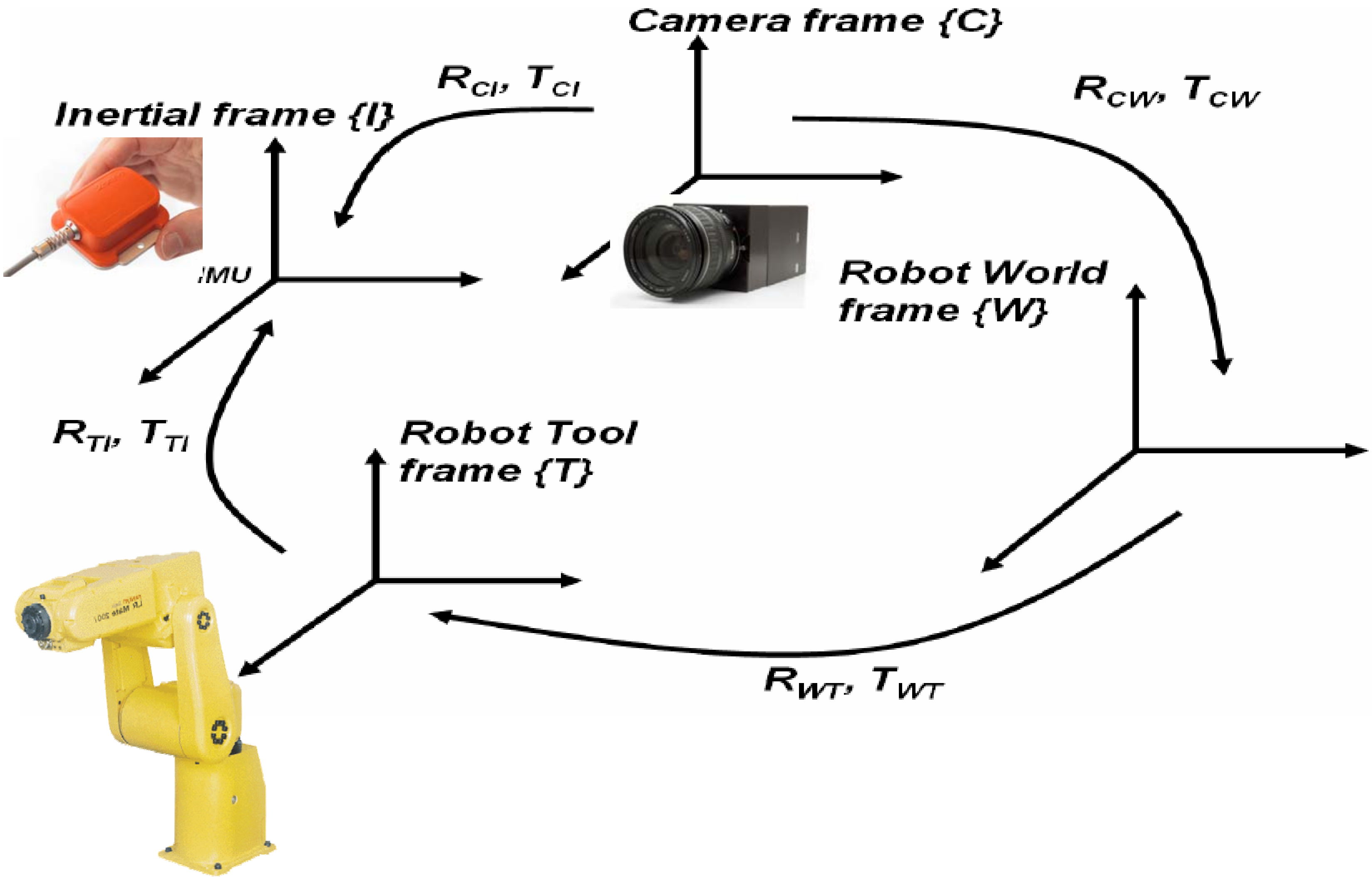
Target code

$1001100000_{binary} = 608_{decimal}$

Vision based Tracking
Target localisation



Hybrid Tracking
Sensors calibration



Hybrid Tracking
Sensors calibration

- IMU Calibration
  - IMU Orientation

Computed by robot

$$R_{CI} = R_{CW} \cdot R_{WT} \cdot R_{TI}$$

From camera calibration

Fixed by user

- IMU Translation

Computed by robot

$$T_{WI} = R_{WT} \cdot T_{TI} + T_{WT}$$

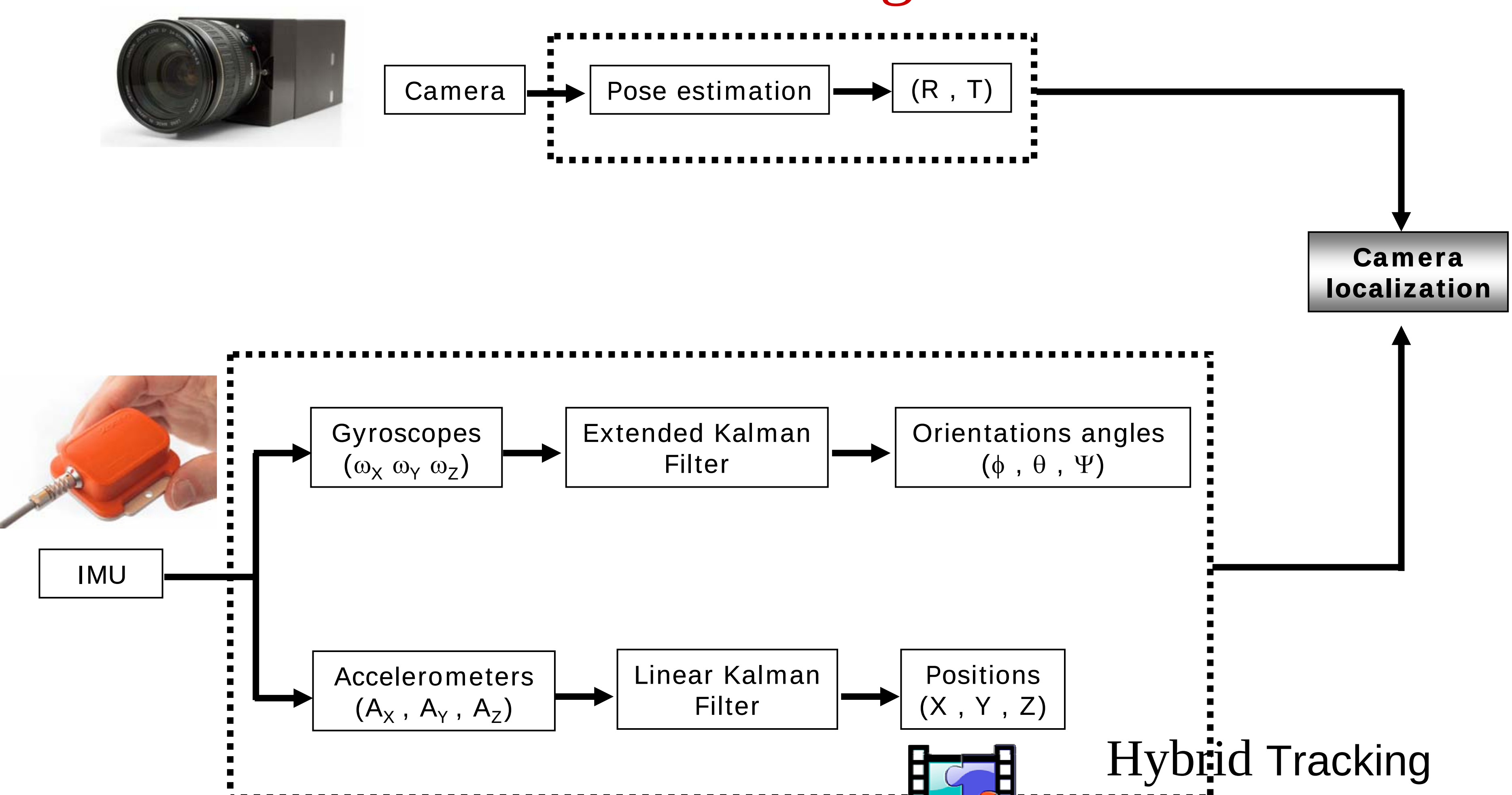
Fixed by user

$$T_{CI} = R_{CW} \cdot T_{WI} + T_{CW}$$

From camera calibration

[Maidi,icinco'2005]

Hybrid Tracking
Target Localisation and occlusion handling



Hybrid Tracking
(Maidi 2007,thesis)

Tracking

•Still open problems in tracking and registration

– Spatial Alignement
  - Optical Distorsions
  - Sensors Sensibility
  - Pose Estimation Errors

– Latency Time
  - Acquisition Delay
  - Processing Time
  - Rendering Time

– Vision conditions
  - Image restoration
  - Shadow management

– Occlusion handling
  - Partial occulsion
  - Total occlusion

– Motion management
  - Abrupt motion
  - Non regular motion

Outcome and future works

- This work allowed to :
- overcome some limitations related to the realization of a tracking system in AR.
- solve the problem of markers registration by establishing a multimodal architecture of tracking and occlusion handling.

- This architecture is composed of :
- registration module of coded targets.
- module of feature points tracking and occlusions management.
- multi-sensors tracking part.

- Experimental results proved that the proposed architecture :
- can track visible, partially or totally occulted targets.
- computes there pose under various camera viewpoints in real time.

- Our future work is to :
- develop a markerless system which uses natural markers instead of coded targets.
- improve the hybrid tracking system by compensating the IMU drift and using another positioning sensor to obtain more accurate positions.

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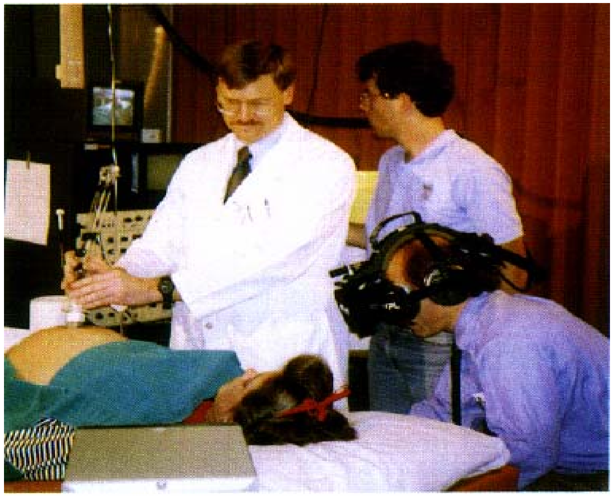
Potential Applications



Medical

Maintaining

Military

edutainment

Some Generic AR projects

- Generic projects

- Sutherland : [Sutherland, 1968] - USA – Video see throught+robot
  - (AR Faisability)

- KARMA : [Feiner et al., 1993 et 1996]-US- mono vision+US

- AR2Hockey : [Ohshira et al., 1998]-Japon- i-glasses+Polhemus
  - (hockey game on real table - puck is virtuel)

- CAMELOT : [Broll et al., 2000] -Germany - Sony LDI100 +2 cameras
  - (Collaborative AR)

- iMAGIS: [Grasset et Gascuel, 2001] - France - i-glasses +Flock of birds
  - (Collaborative AR)

Some AR Industrial Projects

- Boeing : [Neunmann et Majoros, 1998] -US- coded markers
  - **(Aircraft Conception and maintaining),**
- ARVIKA : [Arvika, url 1999]- Germany- coded markers
- **(Conception et maintenance industrielle) http://www.arvika.de**
- ARTESAS : [Arvika, url 2004]- Germany- markerless
  - **(Industrial Conception and maintaining)**
- Starmate : [Schwald et de Laval, 2003]-(ZGDV+EADS)
  - **(Industrial Conception and maintaining)**
- AMRA : [Didier et al., 2005]-France
  - (Train **Conception and maintaining**)

Some links and references

- **http://www.se.rit.edu/~jrv/research/ar/**
- **[Sutherland, 1968]** I. Sutherland (1968). A head-mounted three dimensional display. Computer Conference, pages 757–764, Washington DC. Thompson Books.
- **[Ohshira et al., 1998]** T. Ohshira, K. Satoh, H. Yamamoto, et H. Tamura (1998). Ar2hockey : A case study of collaborative augmented reality. Dans Proceedings of IEEE Virtual Reality Annual International Symposium (VRAIS'98), pages 268–275, Atlanta.
- **[Broll et al., 2000]** W. Broll, E. Meier, et T. Shardt (2000). The virtual round table : a collaborative augmented multi-user environment. Dans Proceedings of ACM Collaborative Virtual Environments, pages 39–46, San Francisco. ACM.
- **[Grasset et Gascuel, 2001]** R. Grasset et J.-D. Gascuel (2001). Environnement de réalité augmentée collaboratif : Manipulation d'objets réels et virtuels. Dans AFIG '01 (Actes des 14èmes journéees de l'AFIG), pages 101–112.
- **[Feiner et al., 1993]** S. Feiner, B. MacIntyre, et D. Seligmann (1993). Knowledge-based augmented reality. Communications of the ACM, 36(7) :52–62.

Some links and references

[Neunmann et Majoros, 1998] U. Neunmann et A. Majoros (1998). Cognitive, performance and system issues for augmented reality applications in manufacturing and maintenance. Dans Proceedings of IEEE Virtual Reality Annual International Symposium (VRAIS'98), pages 4–11, Atlanta. IEEE.

[Arvika, url] Arvika augmented reality for development, production and servicing.

http ://www.arvika.de.

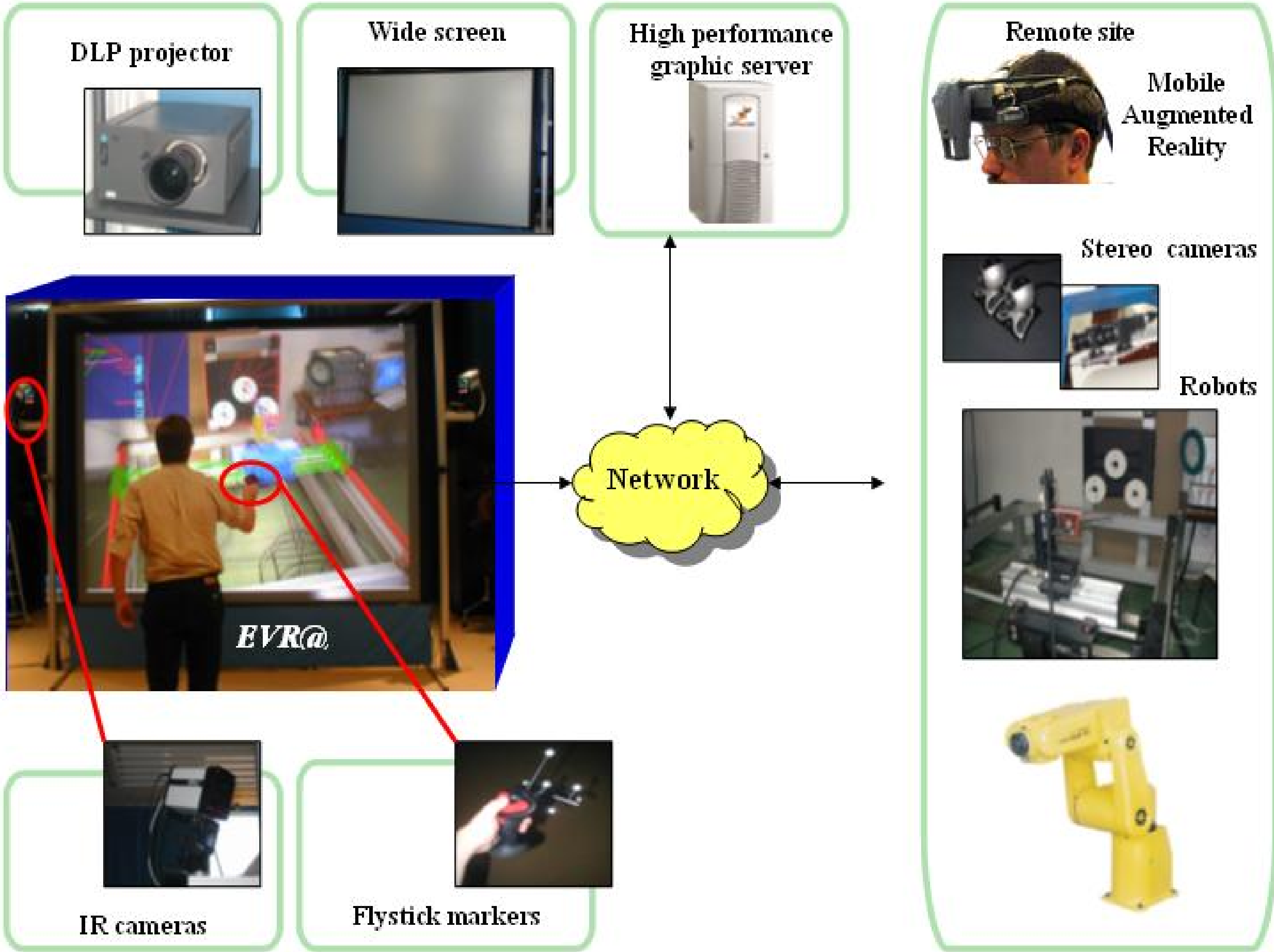
[Schwald et de Laval, 2003] B. Schwald et B. de Laval (2003). An augmented reality system for training and assistence to maintenance in the industrial context. Dans Proc. 11th International Conference in Central Europe on Computer Graphics, Visualization and Computer Vision'2003 (WSCG).

[Didier et al., 2005] J.-Y. Didier, D. Roussel, M. Mallem, S. Otmane, S. Naudet, Q.-C. Pham, S. Bourgeois, C. Mégard, C. Leroux, et A. Hocquard (2005). Amra : Augmented reality assistance in train maintenance tasks. Dans Workshop on Industrial Augmented Reality (ISMAR'05), Vienne, Autriche.

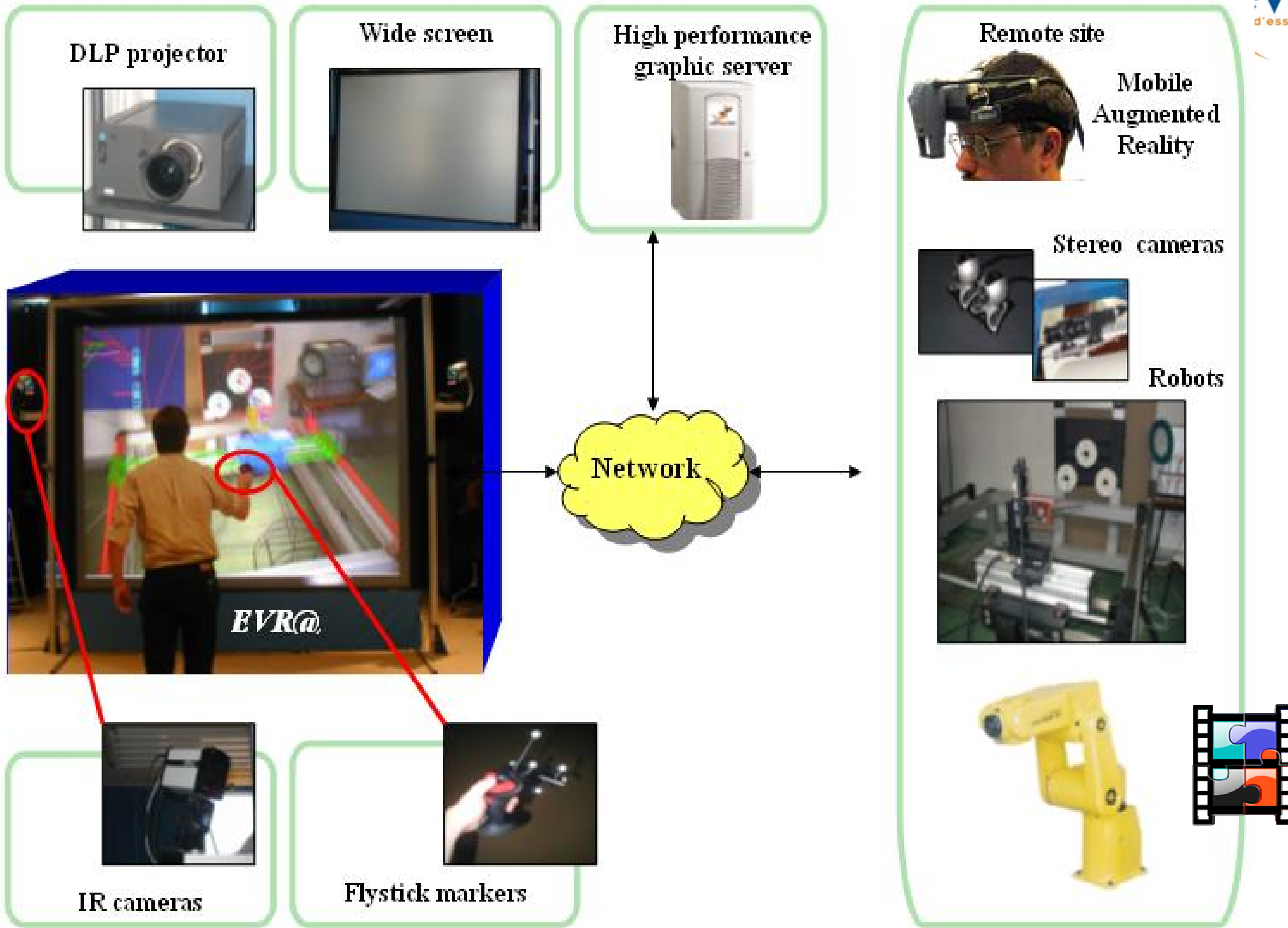
IBISC'Projects

- **Tele Robotique**
- **Industrial application**
- **AR for Archeology**
- **Outdoor AR**

IBISC'EVR@ Platform



IBISC'Project : ARITI



•Démo<evr@> http://lsc.univ-evry.fr/techno/EVRA/

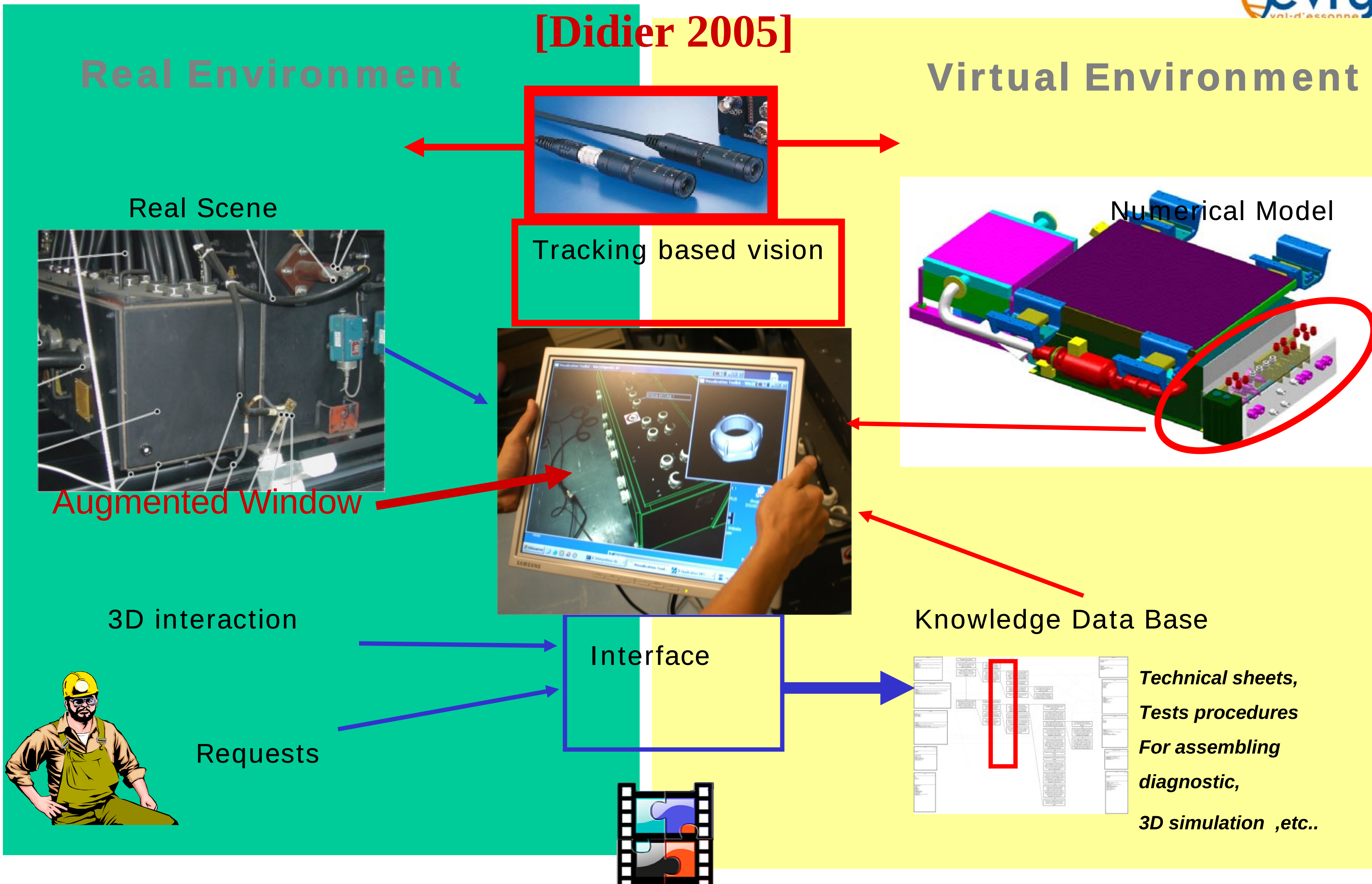
IBISC'Project : AMRA

Assistance à la Maintenance en Réalité Augmentée : AMRA

Consortium : **ALSTOM TRANSPORT, CEA SRSI/LCEI,ActiCM**

Objective : Conception and implementation of an Augmented Reality (AR) system for mobile use in industrial applications such as train maintenance and repairs in industrial sites.

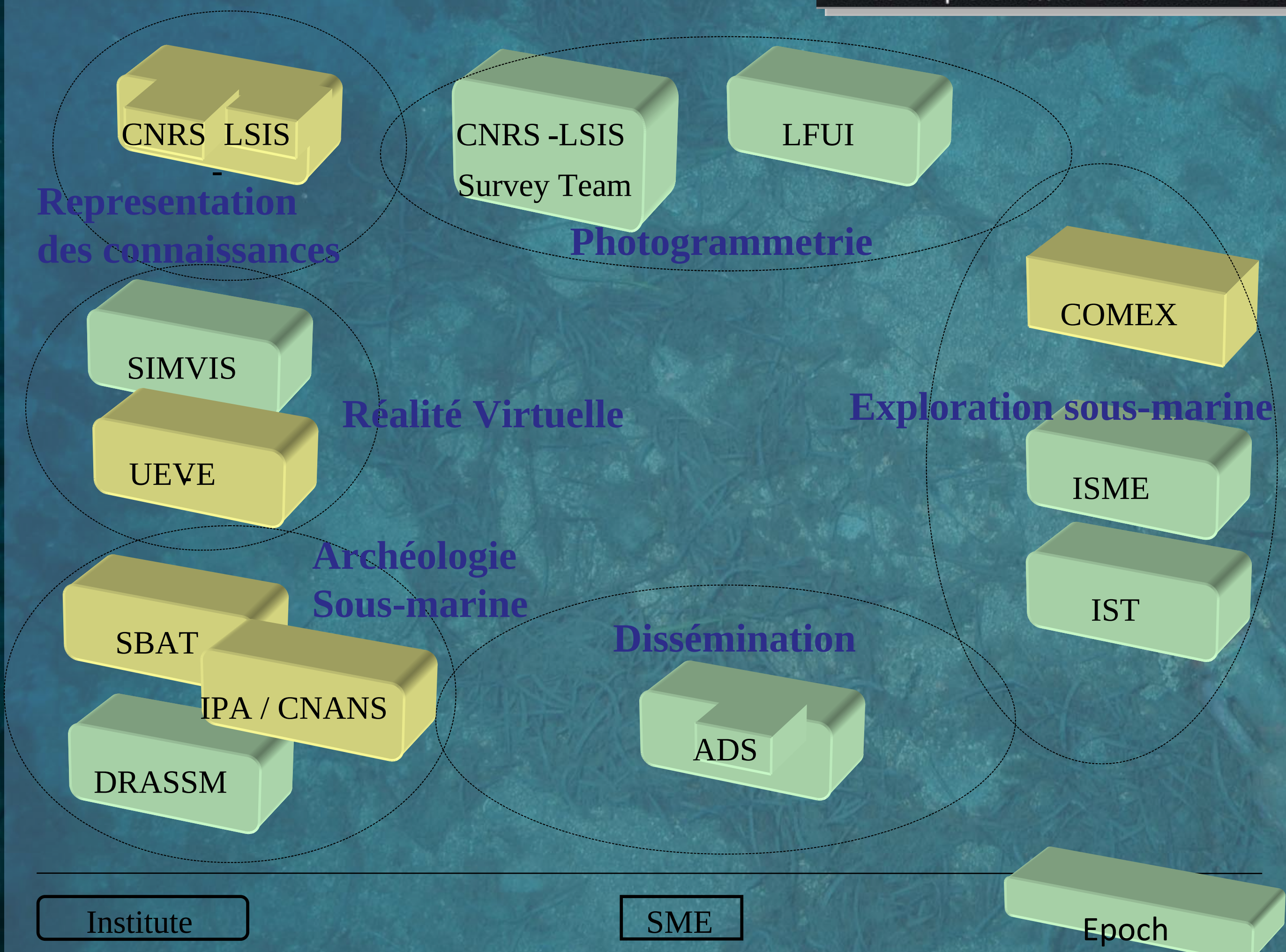
Research : Robust visual based tracking dedicated to augmented window concept (hand held device)


[Didier 2005]
Real Environment
Virtual Environment
Real Scene
Tracking based vision
Numerical Model
Augmented Window
3D interaction
Interface
Knowledge Data Base
Requests
Technical sheets,
Tests procedures
For assembling
diagnostic,
3D simulation ,etc..

Projet Européen VENUS (http://piccard.gamsau.archi.fr/venus/about_fr.html/)

VENUS

Virtual ExploratioN of Underwater Sites



11 partenaires
6 themes

- Archéologie
- Exploration sous marine
- Photogrammetrie
- Réalité Virtuelle
- Représentation des connaissances
- Dissémination

IBISC'Project : AR Venus

European Project VENUS (http://piccard.gamsau.archi.fr/venus/about_fr.html/)

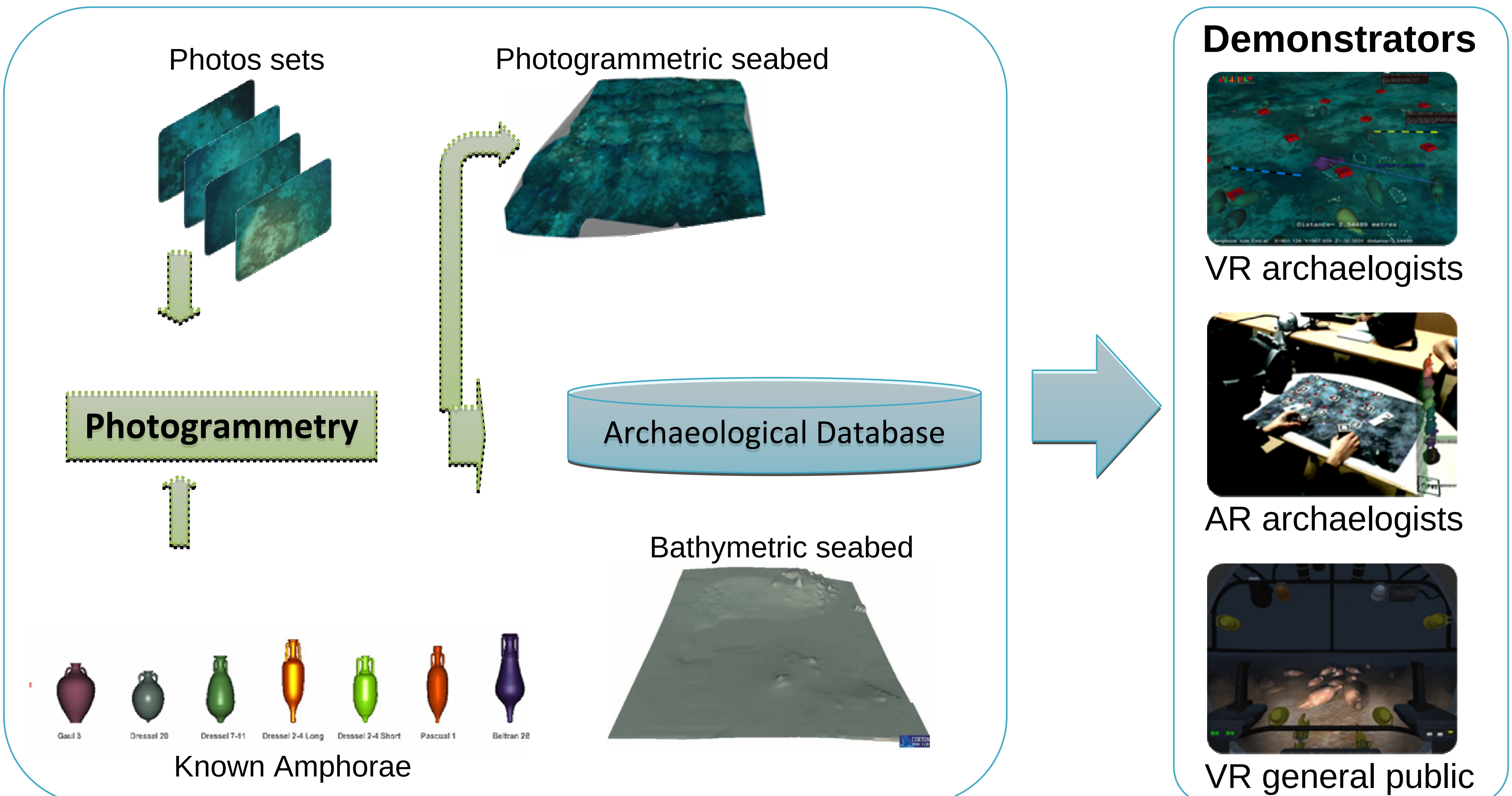
- **VENUS: Virtual ExploratioN of Underwater Sites**
- **Deep wreck sites are out of reach of divers**
- **Provide technological tools for the virtual exploration of deep underwater archaeology sites**

LSIS Marseille

SIMVIS Univ. Hull

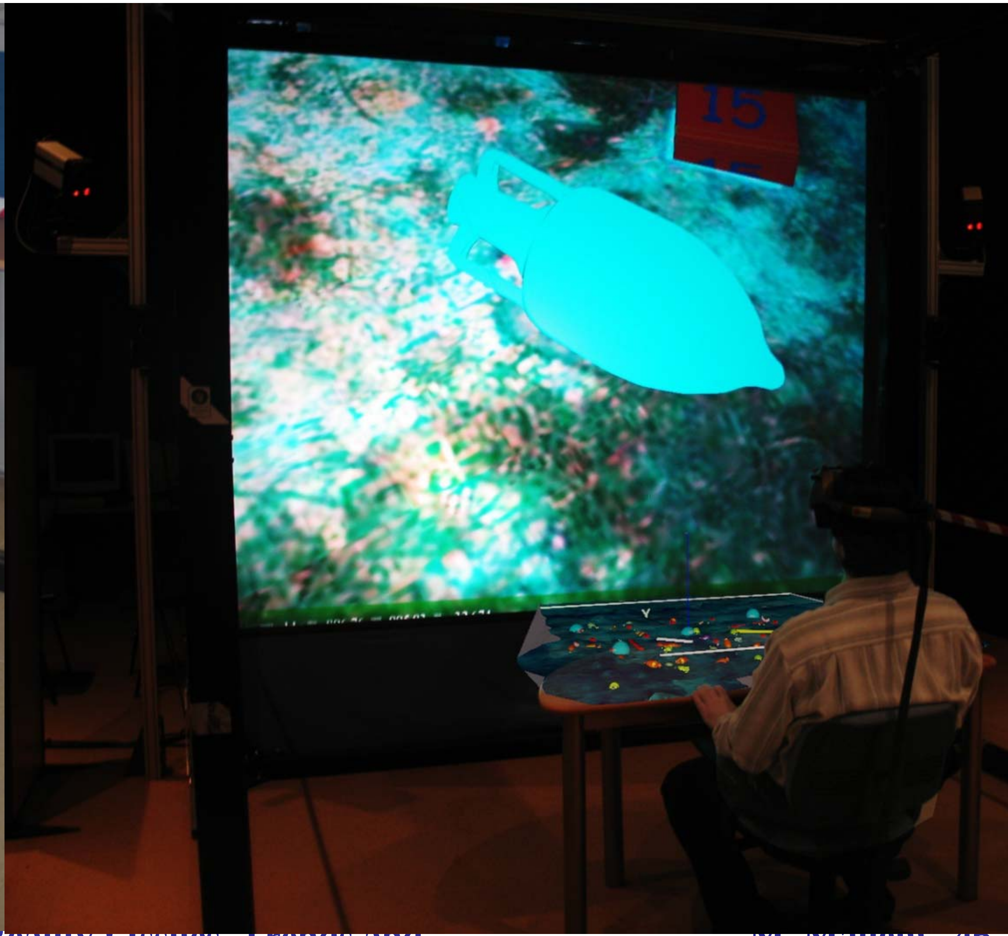
Univ. Evry

IBISC'Project : AR Venus



AR Venus

- **3D Map on a table**
- **AR + VR demonstrators**



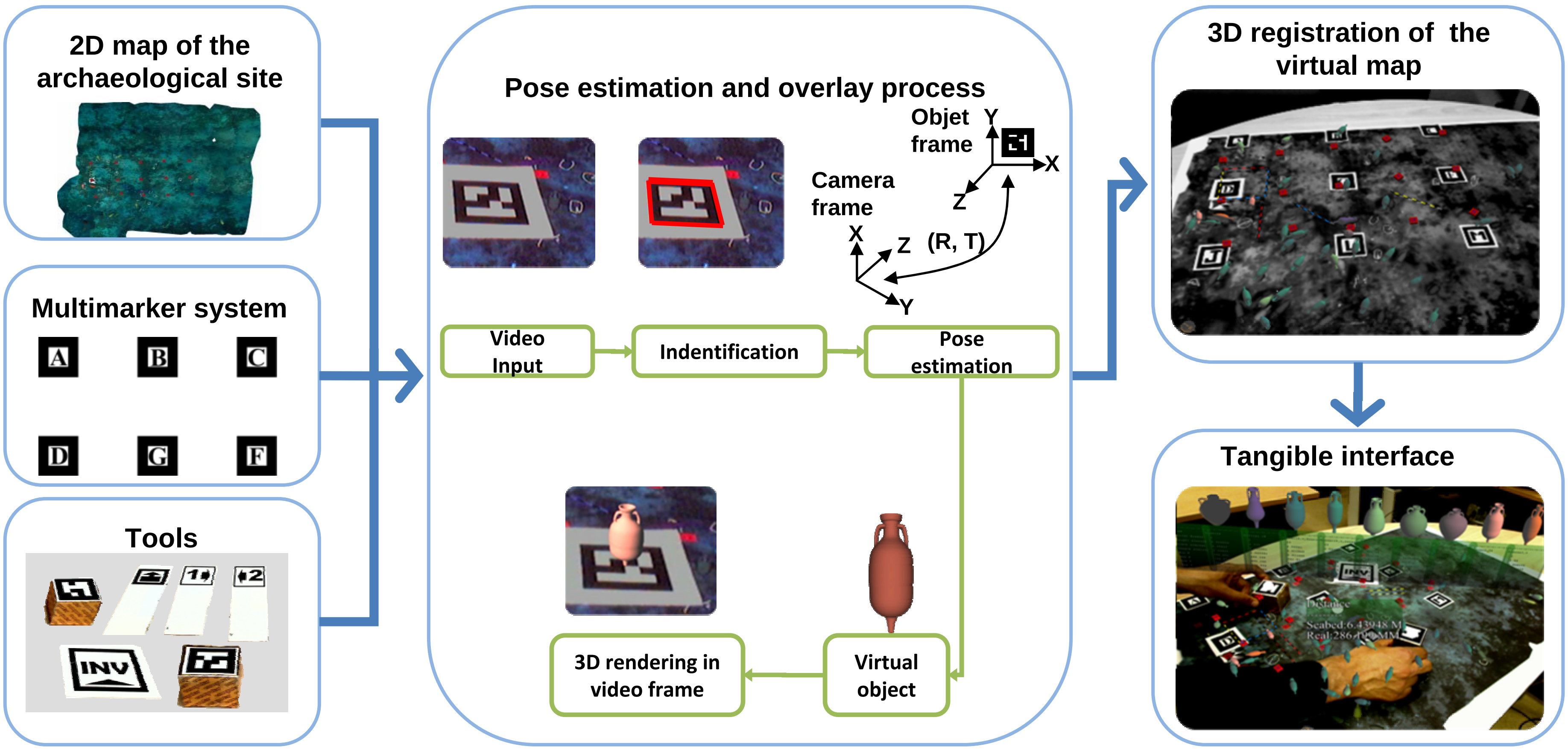
Archaeological Augmented Reality demonstrator - Goals

- Use a real map representing the deep underwater site.
- Enrich this map and complete the real-world perception by adding synthetic elements

- Provide an easy tool to interact with the map with (real) tangible interface

- Using a see-through HMD to see the real map augmented in real time with computer-generated features

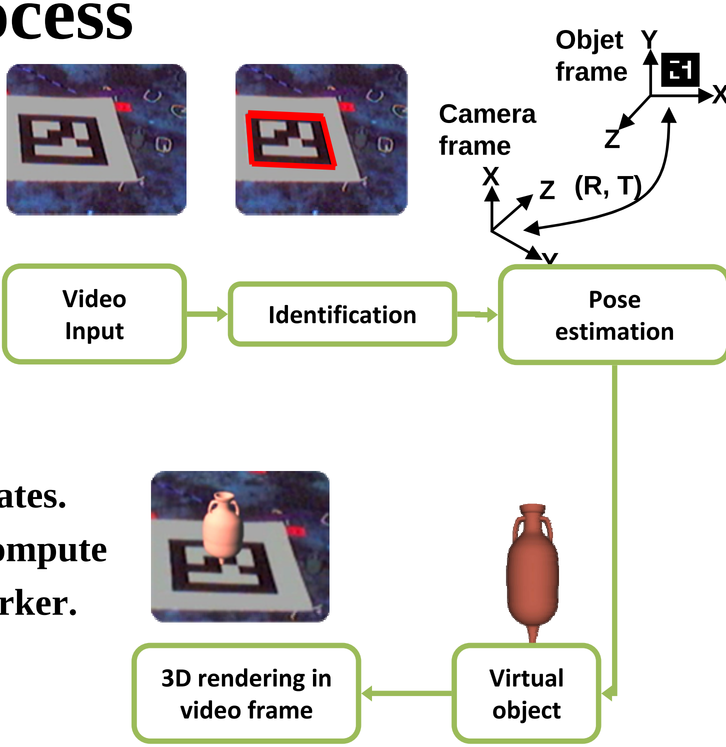
Archaeological Augmented Reality demonstrator - structure



Archaeological Augmented Reality demonstrator

- **Pose estimation and overlay process**
  - **Goal**

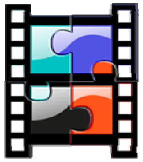
    Project the 3D models of the seabed on the real 2D map using a system of visual markers identification and a pose estimation algorithm.
  - **Registration process**
    - Find all squares in the binary image.
    - mach these targets to some pre-trained pattern templates.
    - The square size and pattern orientation are used to compute the position of the camera relative to the physical marker.
    - Overlay the 3D models on the real scene.



Archaeological Augmented Reality demonstrator
[Haydar 2008]

- **Tangible interface**
  - ➢ **Several moving targets have been associated with virtual tools such as measuring tool and inventory tool:**
    - o **The inventory tool is attached to a single target and displays the site's artifacts inventory.**
    - o **The measuring tool displays the distance within the VE between two attached targets.**
  - ➢ **These tools are activated whenever the camera identifies their corresponding patterns and discarded when they aren't visible anymore.**

  - ➢ **No learning or 3D skills required → tangible tools affordance**



IBISC'Project : RAXENV:

Réalité Augmentée en eXtérieur appliquée aux Métiers de l'ENVironnement

ANR Project

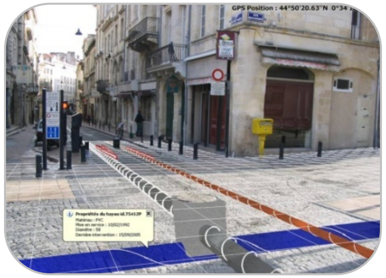
Dec 2006 – June 2010

ANR Projet Raxenv (http://raxenv.brgm.fr/)

Objective

- Navigation and interaction of HO with AR system in differents sites.

Castle restoration



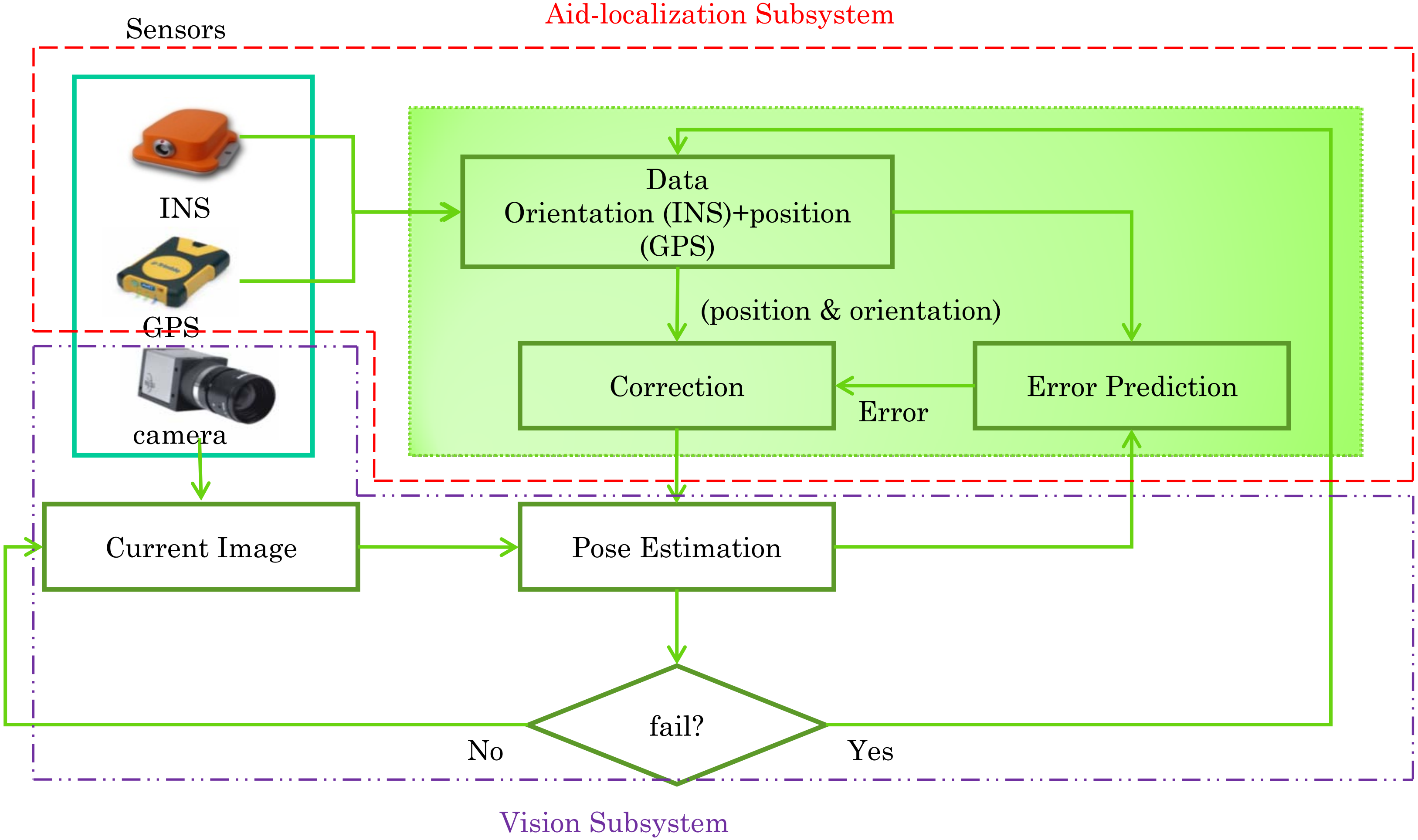
Urbain site

Panoramic site

ZENDJEBIL, VRST'08]

- Technical Goal:
  - Replace vision subsystem when it fails.
- Issues:
  - Each sensor provides data in its own reference frame.
    - ☞ The pose provided by the Aid-Localization subsystem must be aligned with the camera reference frame.
  - The Aid-Localization subsystem is less accurate than vision subsystem.
    - ☞ We need to quantify the accuracy of measurements and improve the estimation of the localization.

Projet ANR Raxenv (http://raxenv.brgm.fr/)



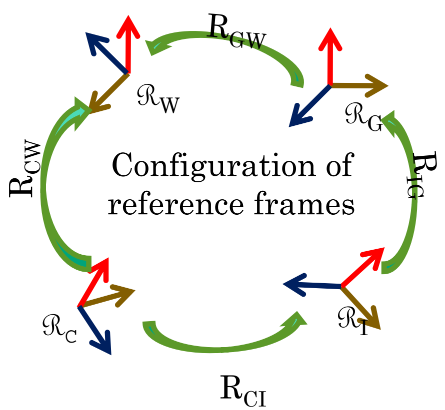
How to align the Aid-Localization subsystem with camera reference frame ?

Two Calibration processes

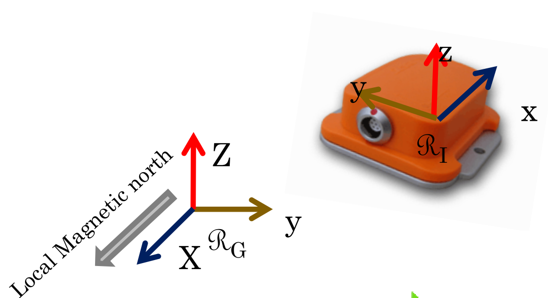
- Inertial/Camera calibration.
- GPS/Camera calibration.

[Zendjebil, Regard'08]

- Inertial/Camera calibration define a relationship between camera and inertial sensor.
  - Why ?
    - To deduce the camera's orientation from the orientation provided by the inertial sensor.
  - How ?

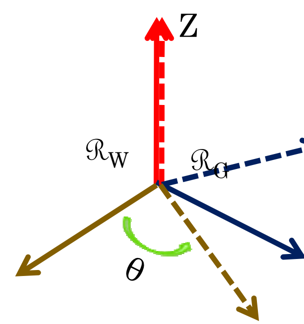


$$R_{CW} = R_{CI} \, R_{IG} \, R_{GW}$$



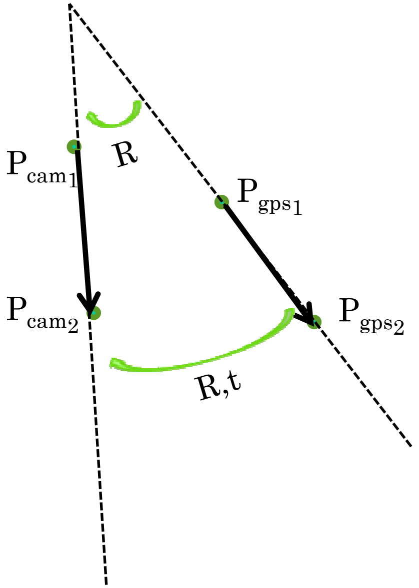
Assumption

To estimate R_{CI} and deduce R_{GW}



the *Z axis of the world reference frame* $\mathcal{R}_W$ *collinear with the Z axis* of the global inertial reference frame $\mathcal{R}_G$

- **GPS/Camera calibration define the transformation to deduce the GPS position with respect to world reference frame.**
  - o **Why ?**
    - ☞ **Deduce the camera's position from the GPS position**
  - o **How ?**



$$p_{cam} = Rp_{gps} + t$$

$$\sum_i^n \|p^i_{cam} - Rp^i_{gps} + t\|^2 \Rightarrow \sum_i^{\frac{n}{2}} \|\overrightarrow{N}^i_{cam} - R\overrightarrow{N}^i_{gps}\|^2$$

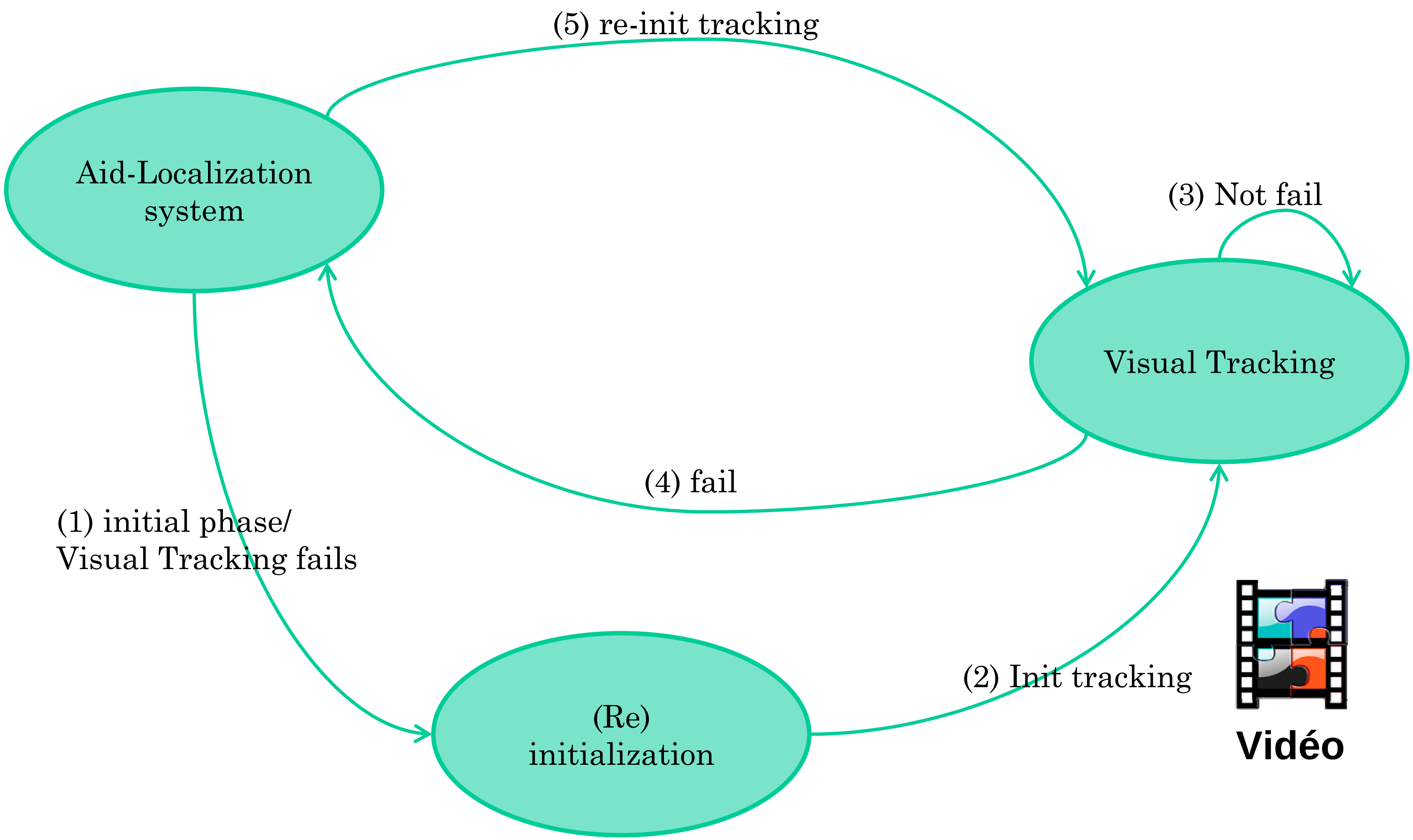
$$\overrightarrow{N}^i_{gps} = p^j_{gps} - p^i_{gps}$$

$$\overrightarrow{N}^i_{cam} = p^j_{cam} - p^i_{cam}$$

$$i = 1..\tfrac{n}{2}$$

$$j = \tfrac{n}{2} + 1..n$$

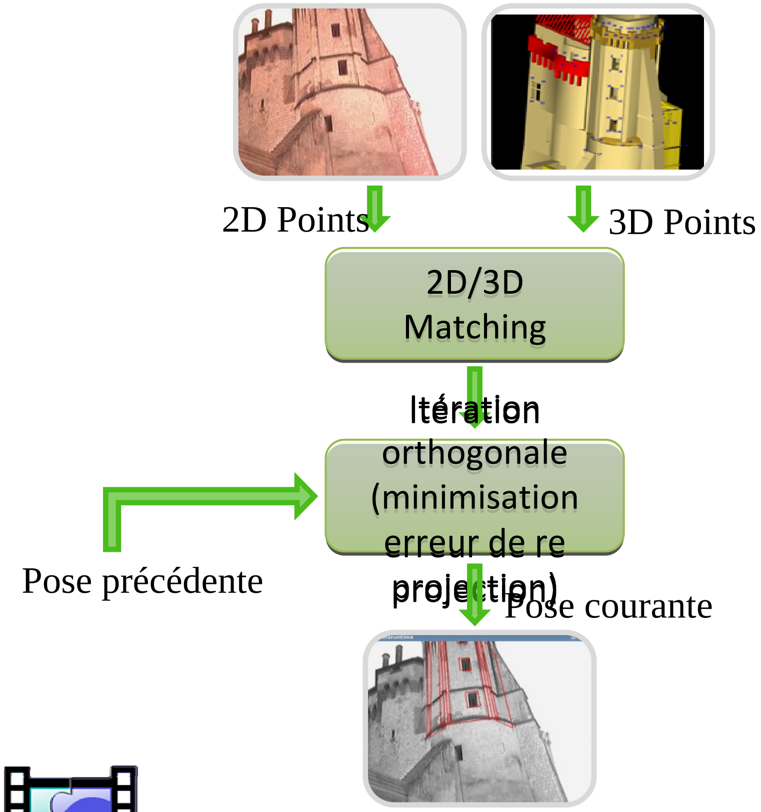
- Deduce camera pose from the Aid-Localization subsystem data and transformations obtained by the calibration.
  - Simple.
  - Efficient.
  - Do not require heavy assumptions.

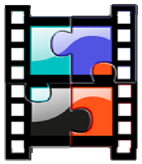

(5) re-init tracking
Aid-Localization system
(3) Not fail
Visual Tracking
(4) fail
(1) initial phase/ Visual Tracking fails
(2) Init tracking
(Re) initialization
Vidéo

Scenario : Saumur Castle

> Vision based Tracking

- Pose Estimation :
  - Based on interests points.
  - 2D/3D matching
  - Pose Estimation(orthogonal Iteration).





Video

- The Aid-localization subsystem is less accurate than vision subsystem.
  - We need to quantify the quality of measurements and improve the estimation provided by the aid-localization subsystem.
- Our error = the difference with respect to the camera pose provided by vision subsystem.
- When the vision fails we need to predict this error
  - Record the offset between the hybrid sensor and camera pose during visual tracking.
  - Predict the offset made by hybrid sensor using Gaussian process when the visual tracking fails.
  - Improve the localization estimation.

Outline of talk

- Introduction
- Sensors modeling and calibrating
- Visual and Hybrid tracking
- AR Projects
- Conclusions and challenges

AR Challenges

- **Researchs :**
  - Software architecture for application prototyping
  - tracking and registration problem is one of the most fundamental challenges, which is still open.
  - Ubiquitous localization is also still open
  - 3D real time natural interaction

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