



# Suivi de pose basé modèle pour l'asservissement d'un drone

Céline Teulière

CEA LIST, Fontenay-aux-Roses

[celine.teuliere@cea.fr](mailto:celine.teuliere@cea.fr)



lagadic



LIST – DTSI

1<sup>er</sup> avril 2010

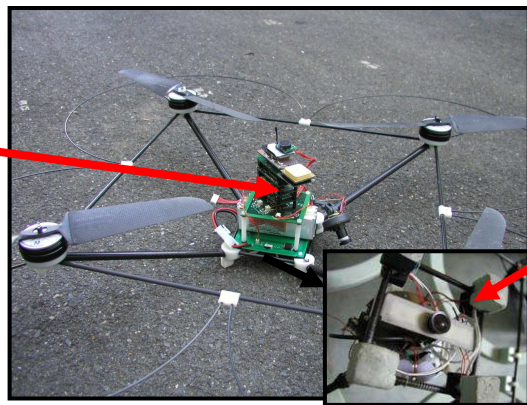


## Suivi de pose basé modèle

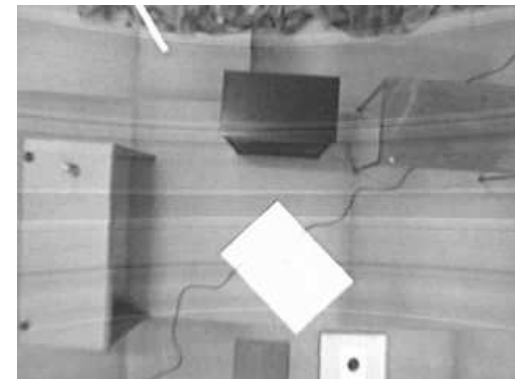
- **Objectif : Estimation de la pose (position + orientation) d'un drone**
- **Hypothèses :**
  - ✓ Environnement structuré
  - ✓ Modèle 3D connu (contours)
- **Intérêt :**
  - ✓ Utilisation des contours -> fréquents et robustes
  - ✓ Précision



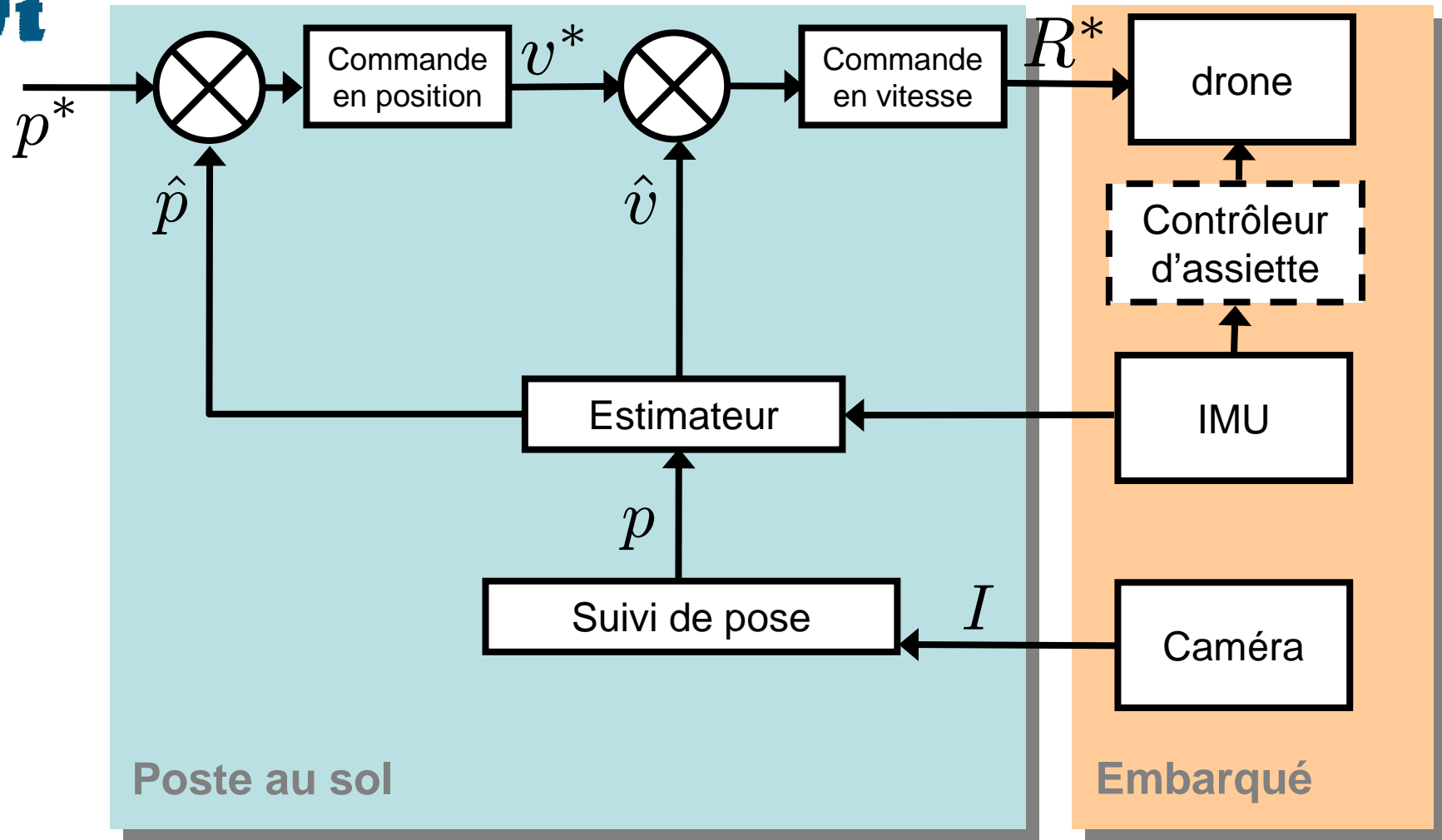
Centrale  
inertielle  
(IMU)



Caméra



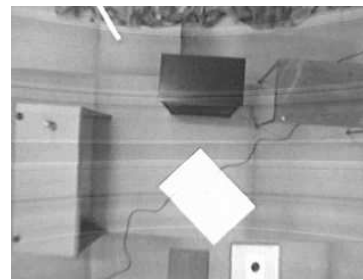
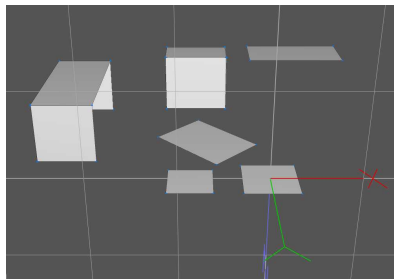
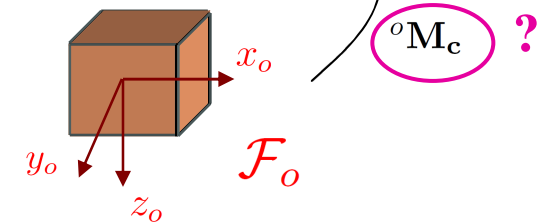
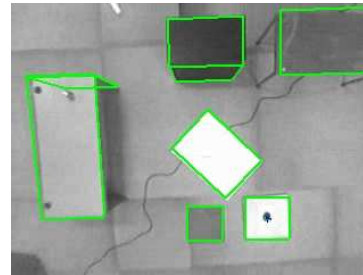
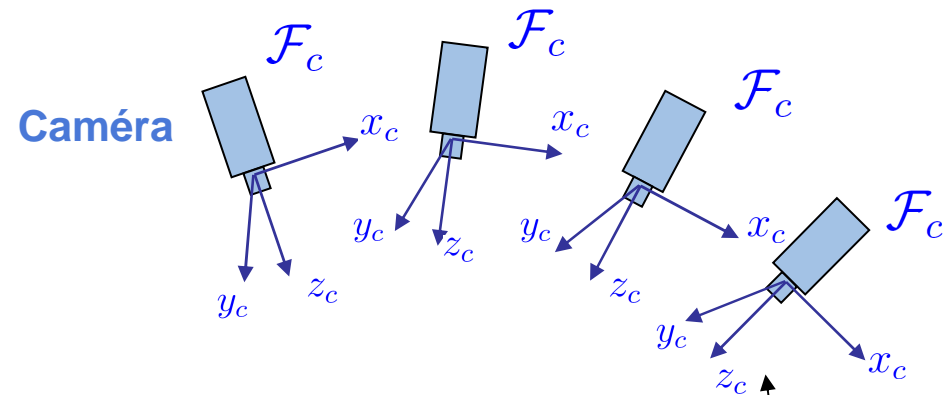
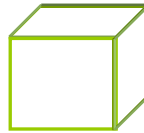
## Aperçu



# Suivi de pose basé modèle

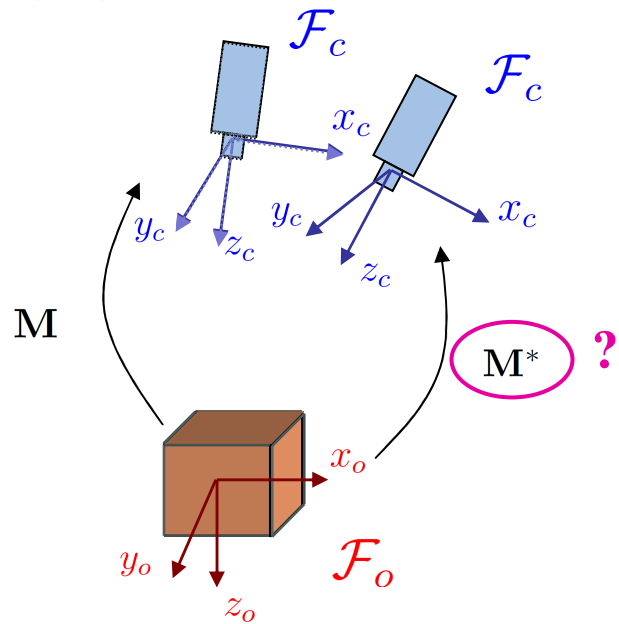
- Suivre la pose 3D de la caméra par rapport à l'environnement

Modèle 3D



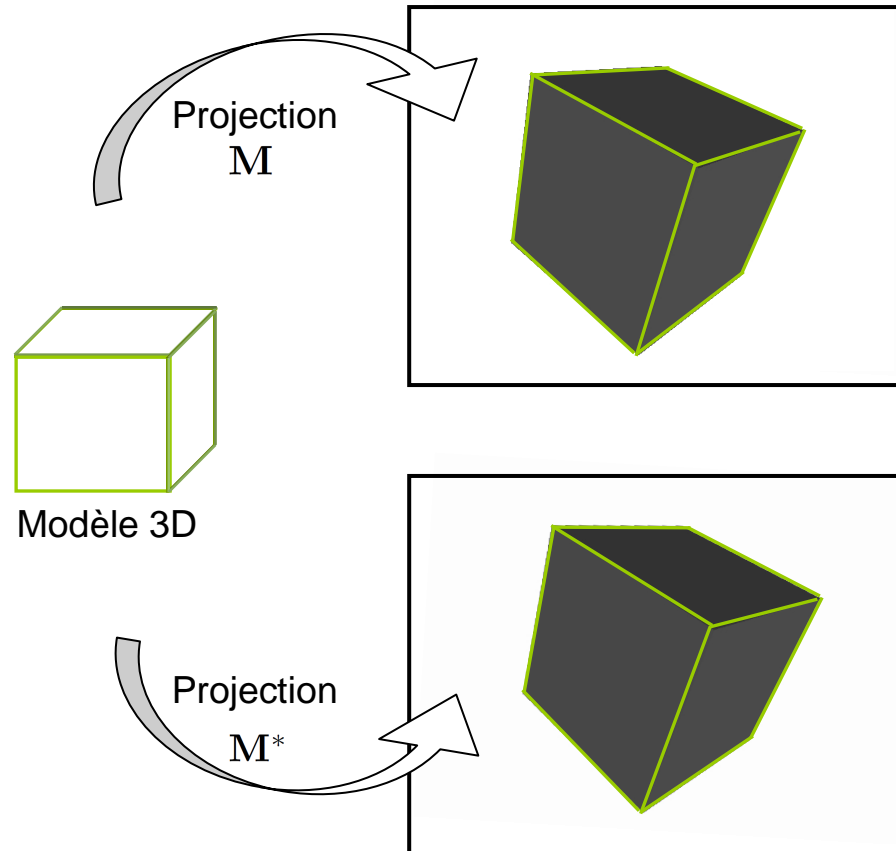
# Principe

## Scène réelle



Problème : comment trouver  $M^*$  ?

## Plan image



## Formulation

$$\begin{aligned} se(3) &\mapsto SE(3) \\ \xi &\mapsto \mathbf{M} = \exp(\xi) \end{aligned}$$

➤ **Exponential map**

$$\mathbf{M}^* = \mathbf{M}e^{\xi} \quad \xi = \begin{bmatrix} [\boldsymbol{\omega}]_{\times} & \mathbf{v} \\ 0 & 0 \end{bmatrix}$$

➤ **Paramétrisation avec les coordonnées exponentielles canoniques**

$$\mathbf{v} = (\mathbf{v}, \boldsymbol{\omega})^{\top}$$

➤ **Vecteur de 6 paramètres**

## Différentes approches

### ➤ Méthodes de type optimisation :

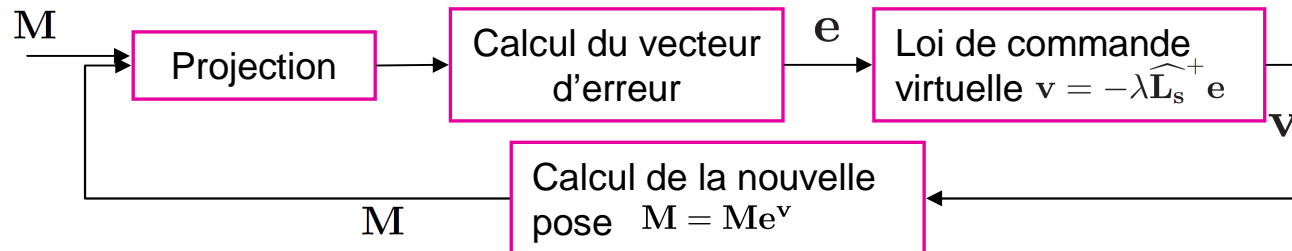
$${}^c\widehat{\mathbf{M}}_w = \underset{{}^c\mathbf{M}_w}{\operatorname{argmin}} \sum_{i,j} d_{\perp}(E_i, e'_{i,j})$$

$$d_{\perp}(E_i, e'_{i,j}) = d_{\perp}(l_i({}^c\mathbf{M}_w), e'_{i,j})$$

- ✓ Formulation sous forme des moindres carrés [Drummond-02]

$$\mathbf{e} = \|\mathbf{J}\mathbf{v} - \mathbf{d}\|^2 \quad \mathbf{v} = \mathbf{J}^+\mathbf{d}$$

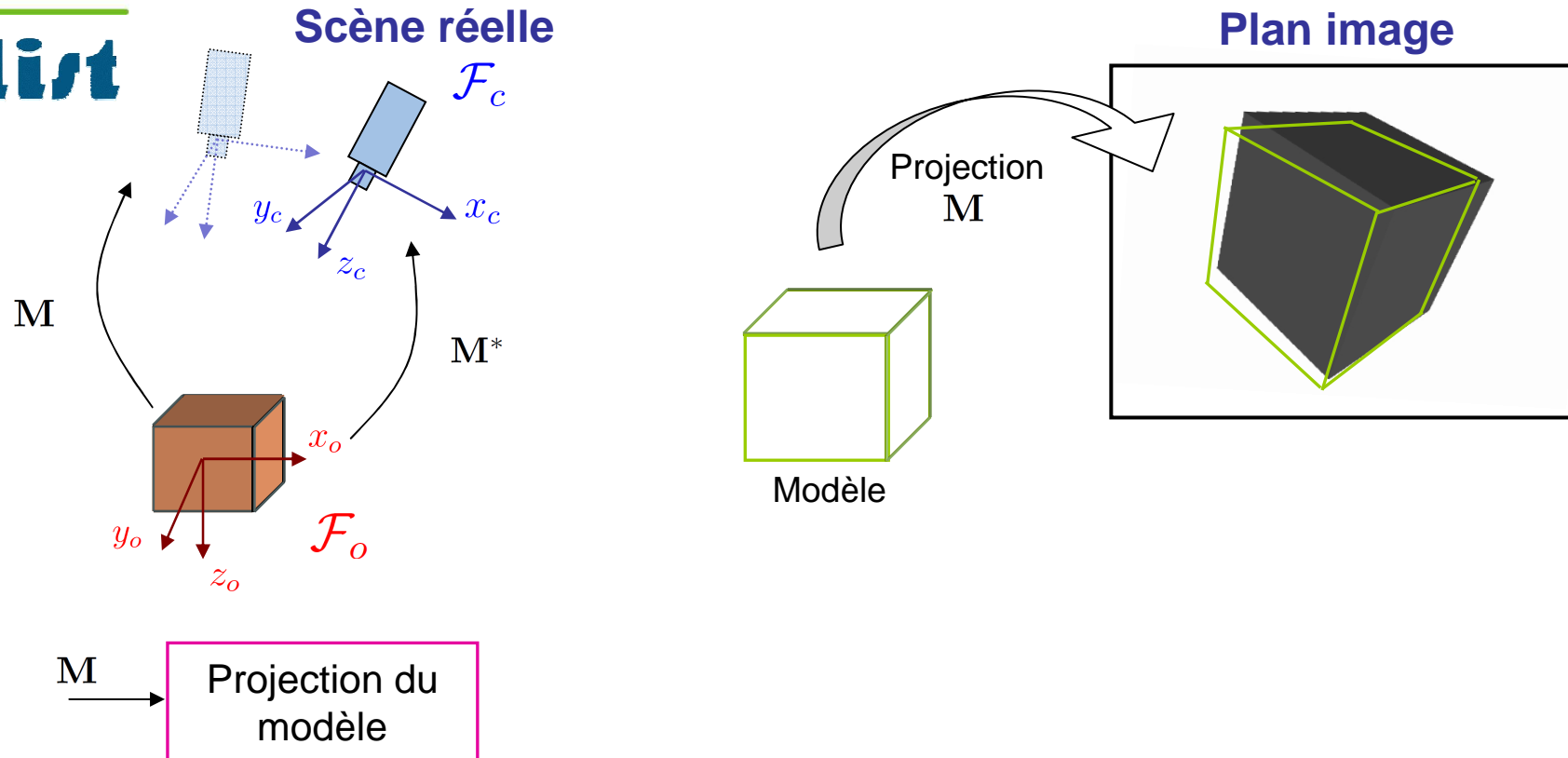
- ✓ Asservissement visuel virtuel (VVS) [Comport-06]



### ➤ Approches Bayésiennes

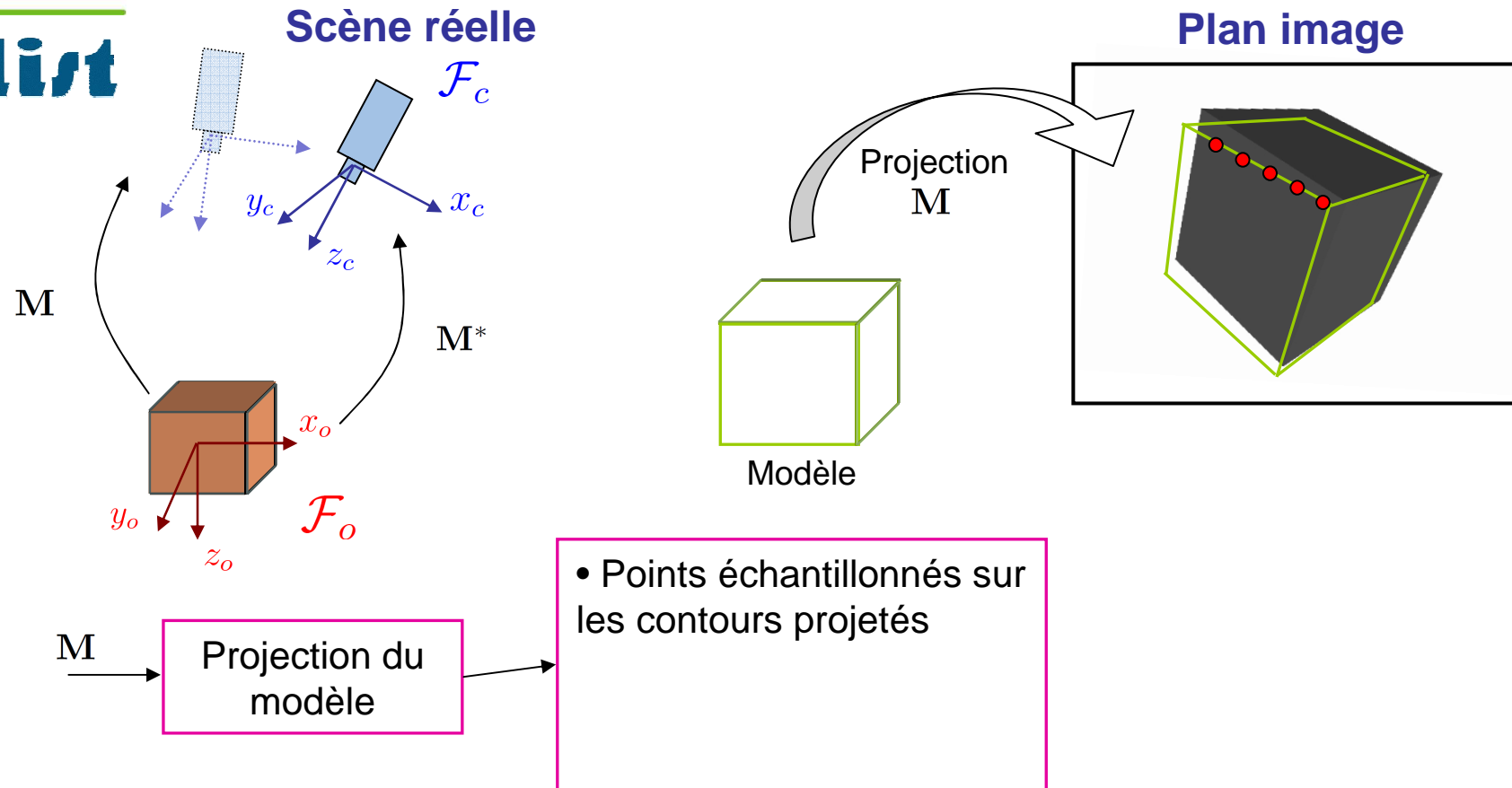
- ✓ Filtrage particulaire [Pupilli-Calway]

# Asservissement Visuel Virtuel

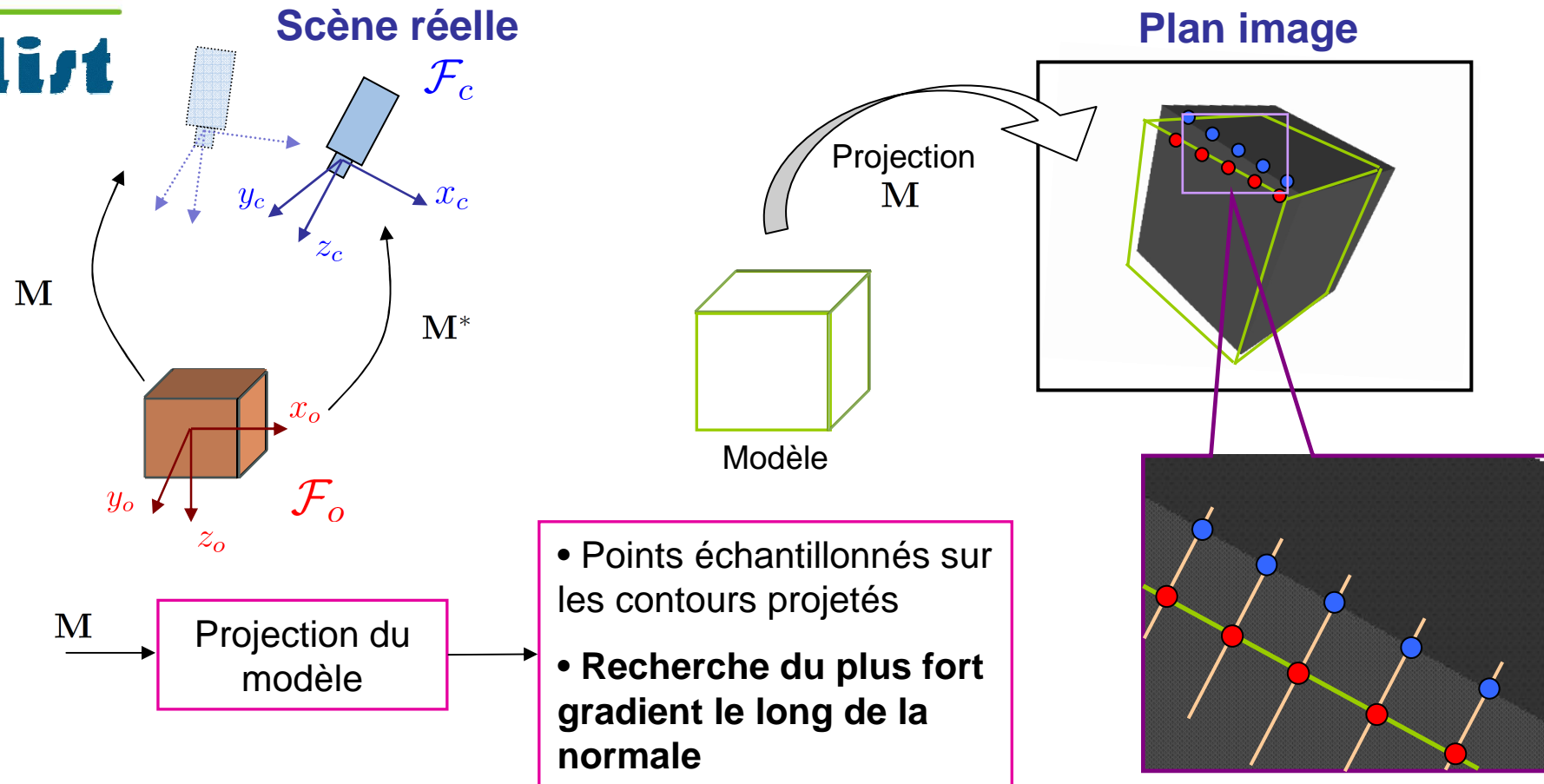




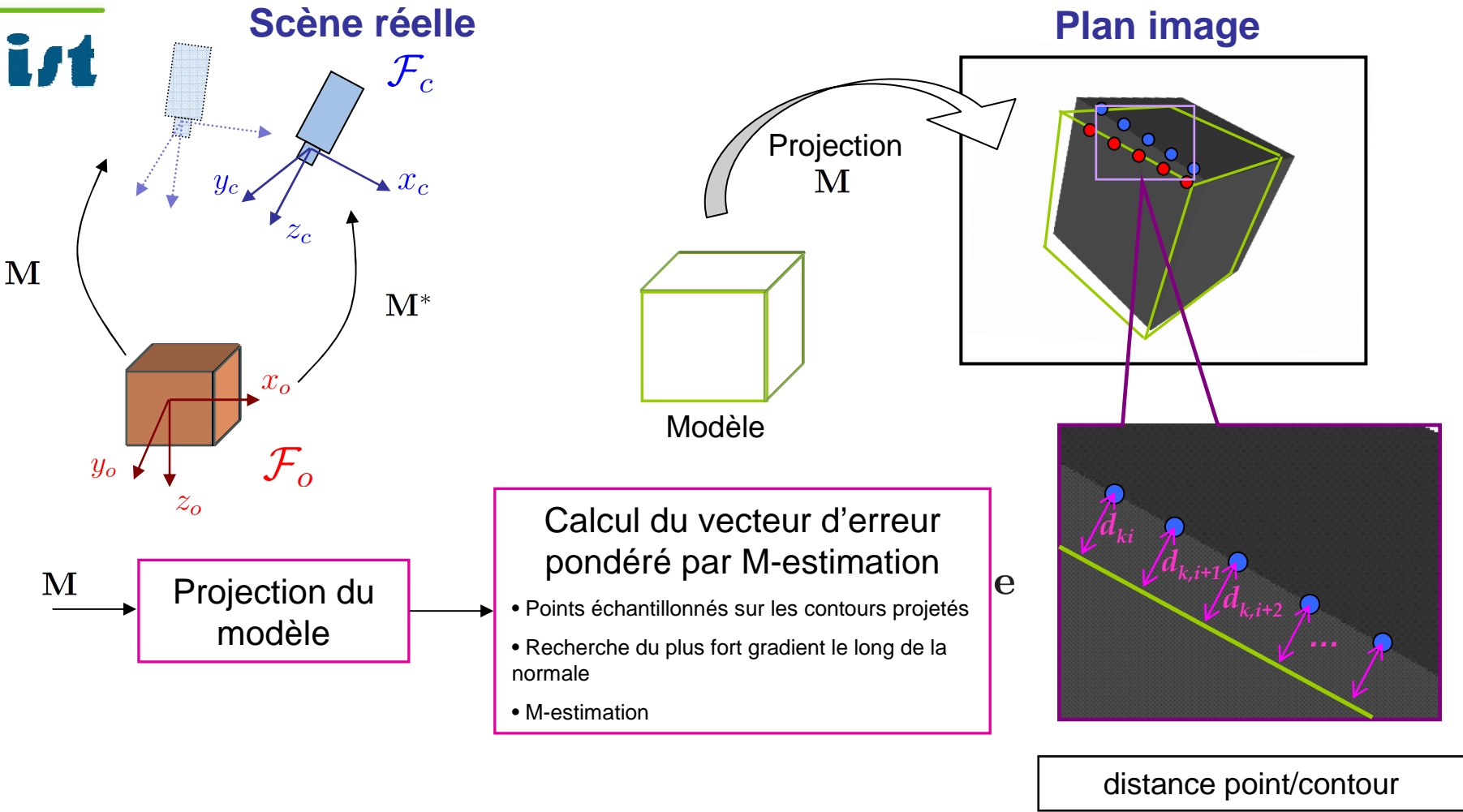
## Asservissement Visuel Virtuel



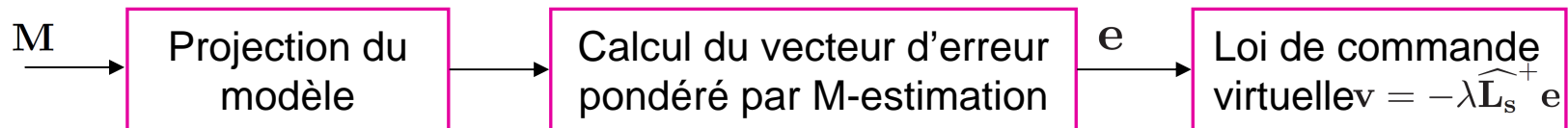
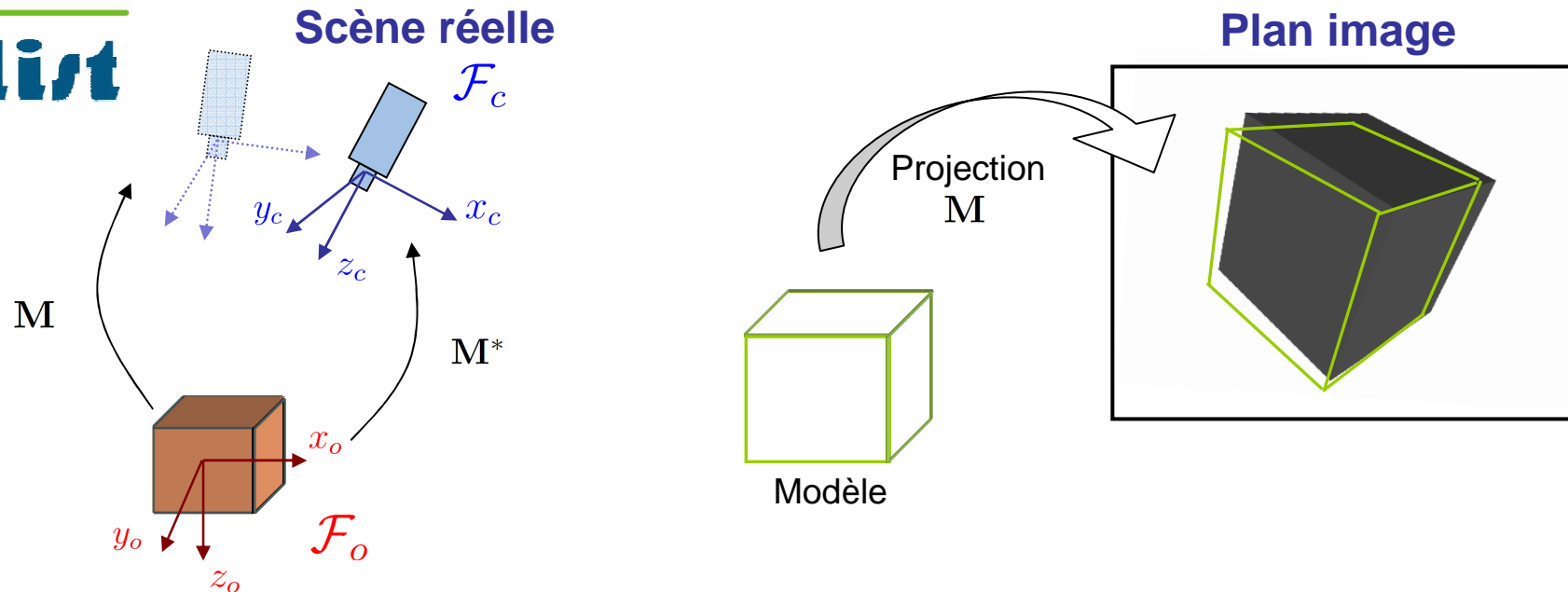
# Asservissement Visuel Virtuel



# Asservissement Visuel Virtuel

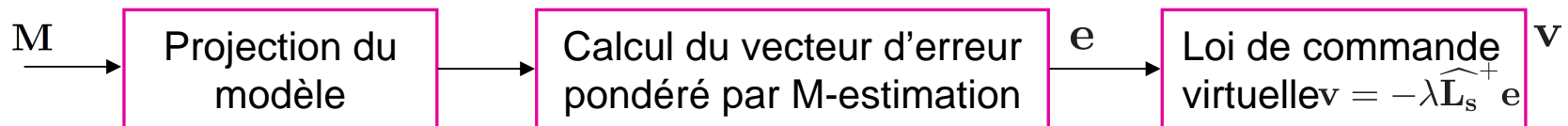
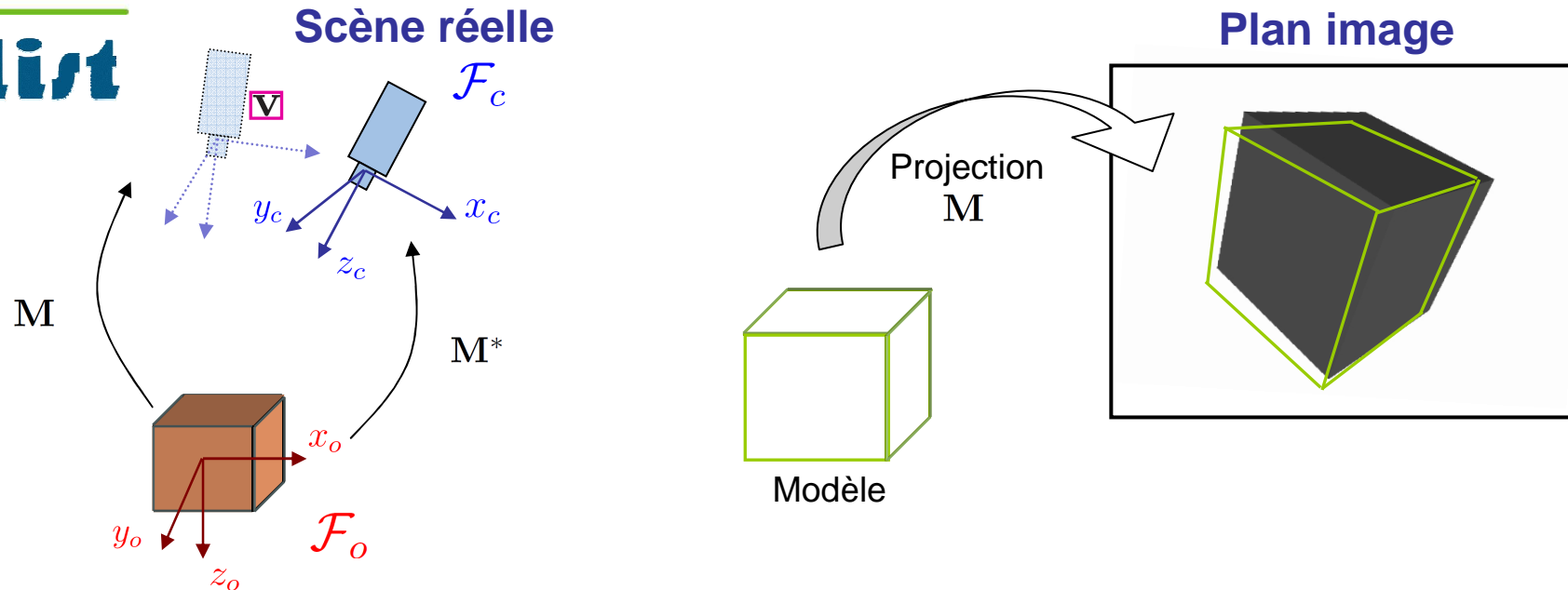


# Asservissement Visuel Virtuel

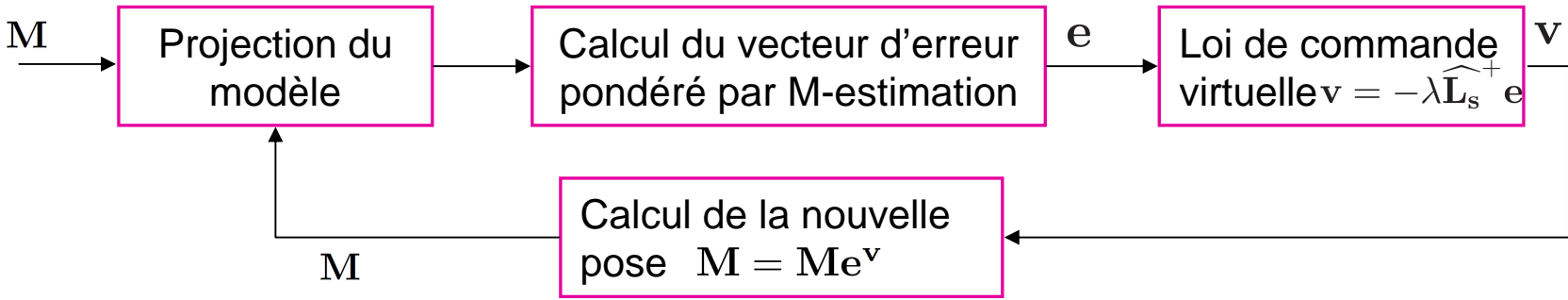
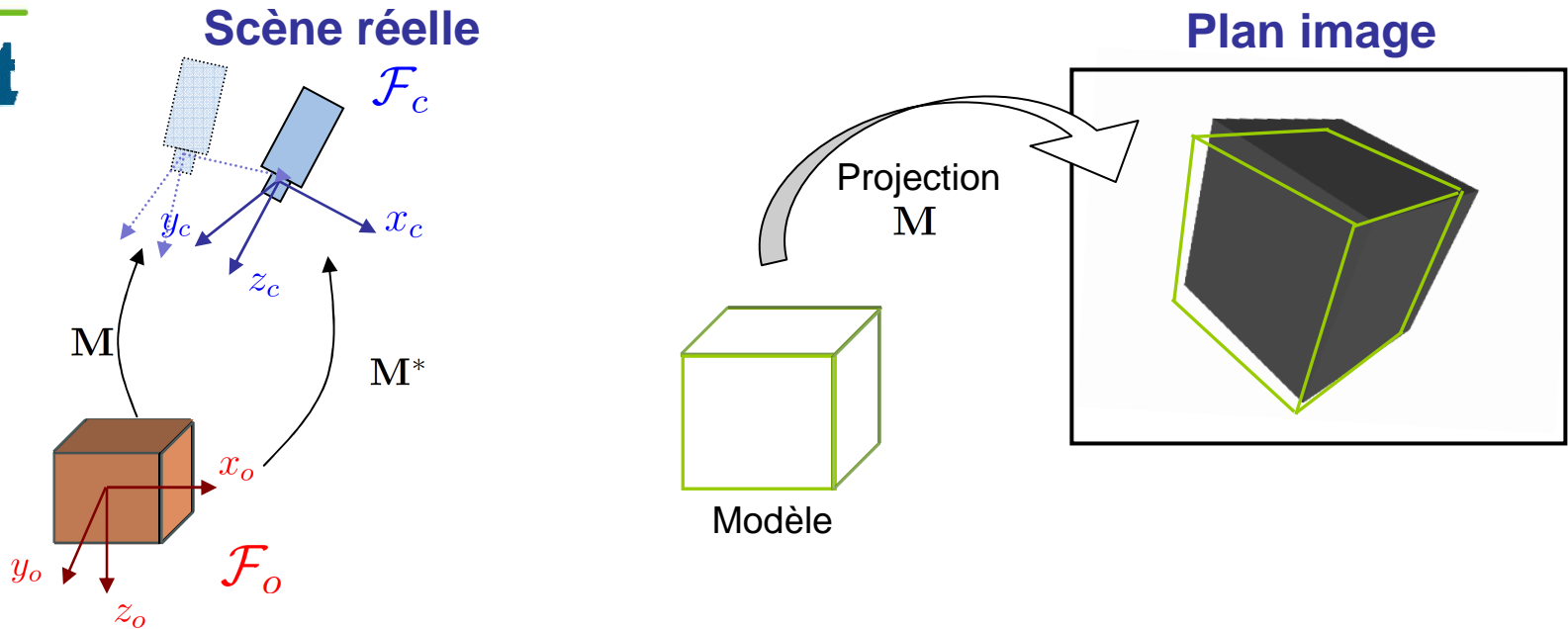


Distance point/contour:  $L_{d_i}$  connu

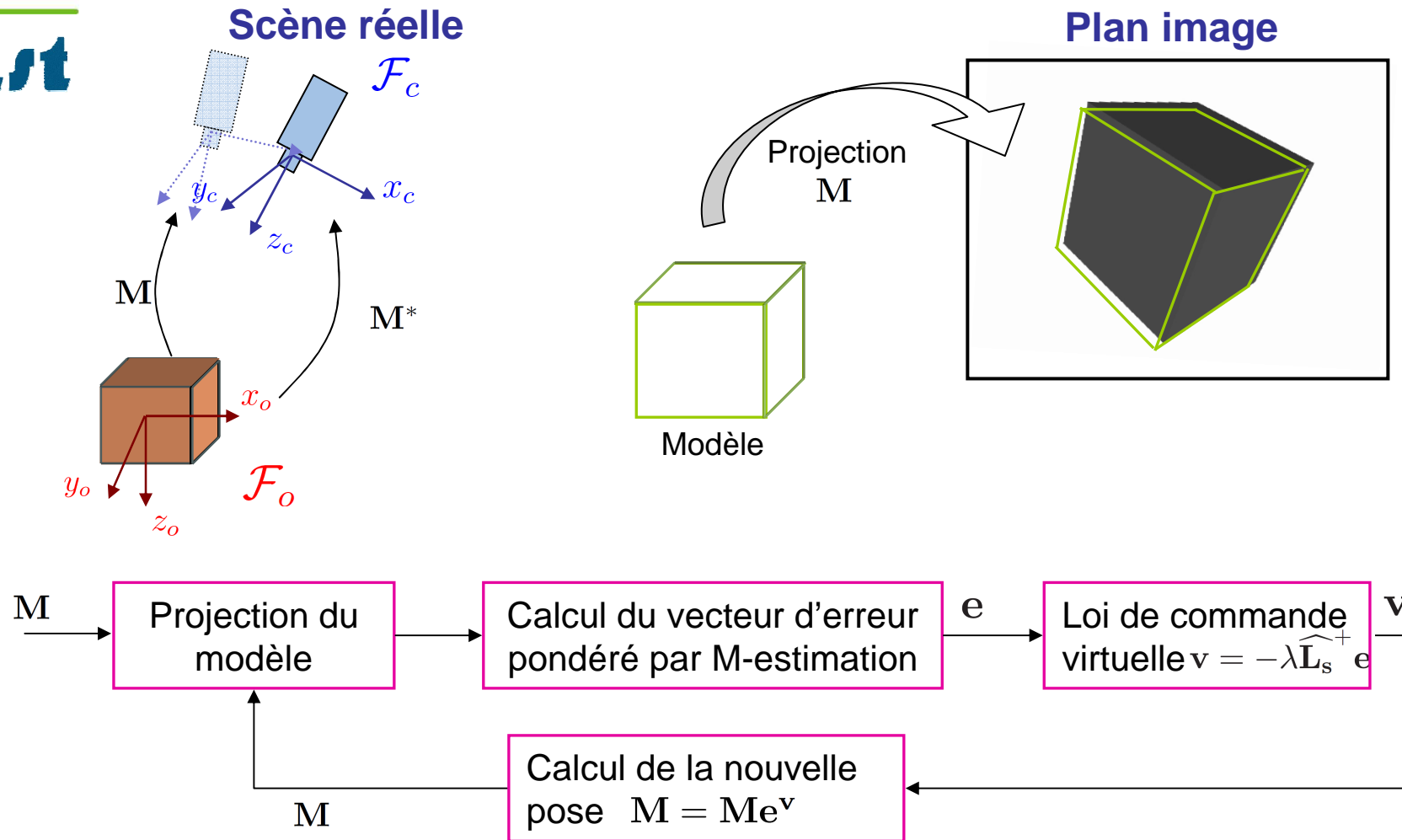
# Asservissement Visuel Virtuel



# Asservissement Visuel Virtuel

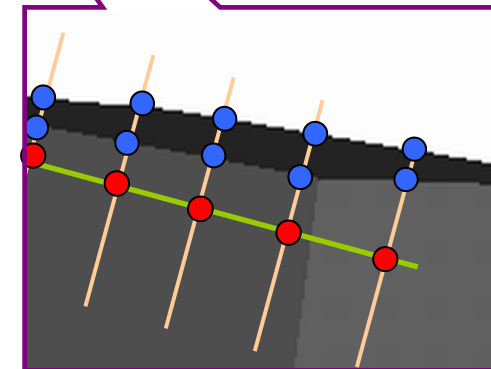
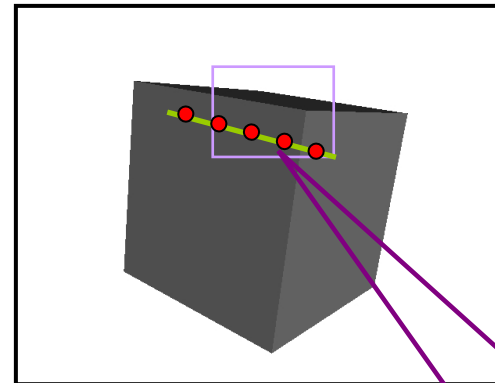


# Asservissement Visuel Virtuel



## Limitations

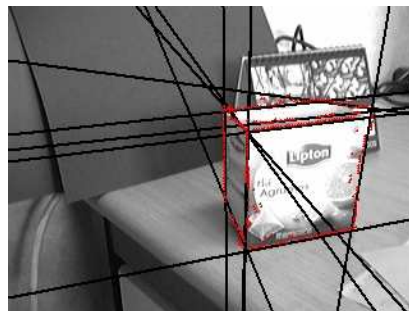
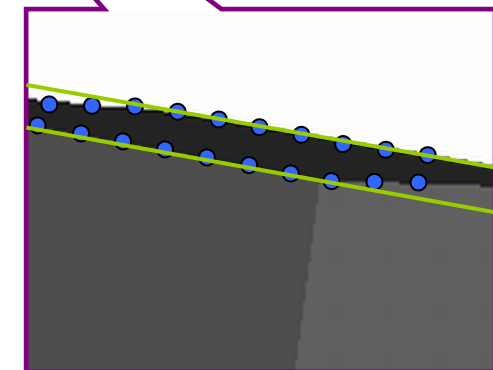
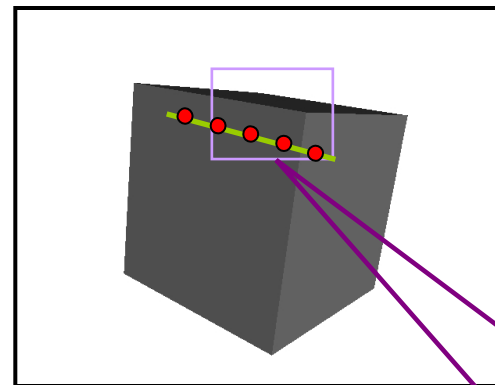
- **Bas niveau (traitement d'image) :**
  - ✓ Mauvaise localisation des points : plusieurs forts gradients le long de la normale ?
  
- **Haut niveau (déplacement de la caméra) :**
  - ✓ Mauvaise localisation de la caméra : recherche à partir d'une position prédite ?





## Approche multi-hypothèses

- Plusieurs points de forts gradients sont mémorisés
- Les hypothèses sur les points sont converties en hypothèses sur les lignes
  - ✓ Classification par k-mean



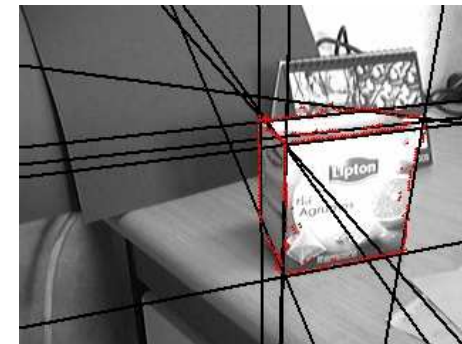
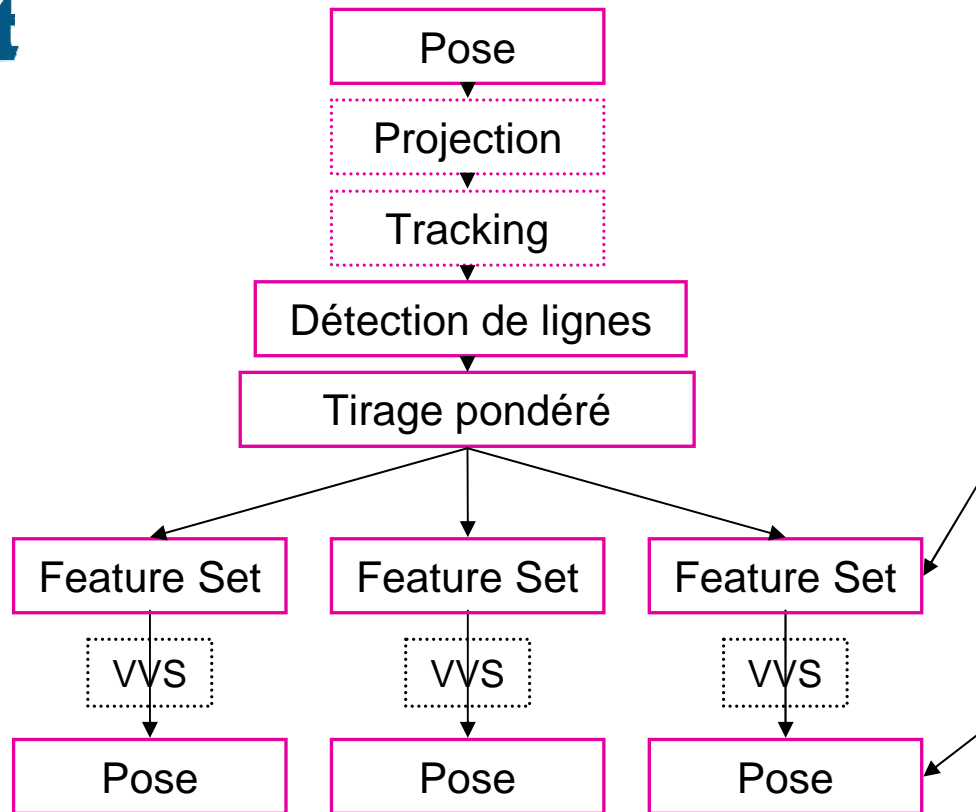
Pose

Projection

Tracking

Détection de  
lignes

## Approche multi-hypothèses

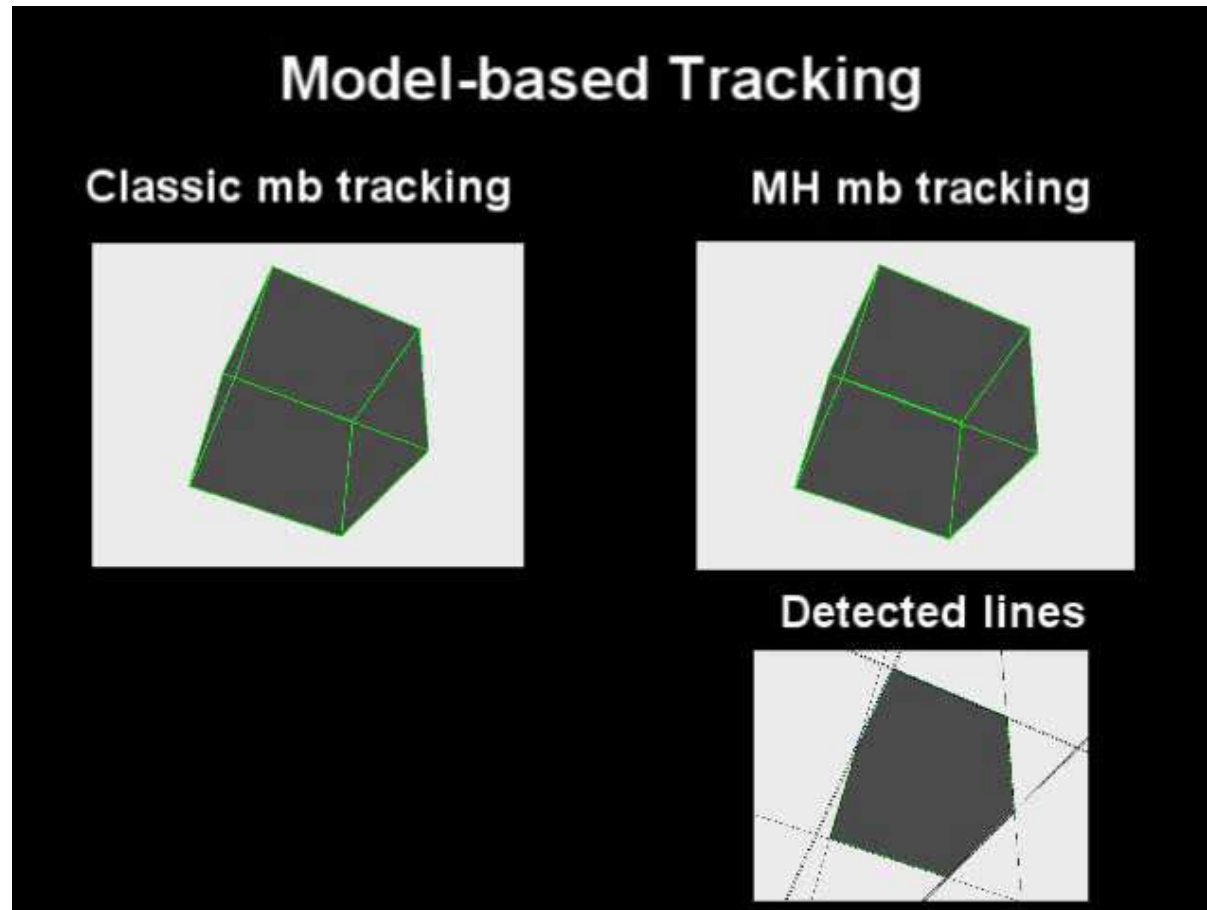


- Tirage pondéré parmi les lignes candidates et calcul de la pose correspondante
- Plusieurs hypothèses pour la pose de la caméra

On conserve la pose qui donne le plus petit résidu lors de la minimisation

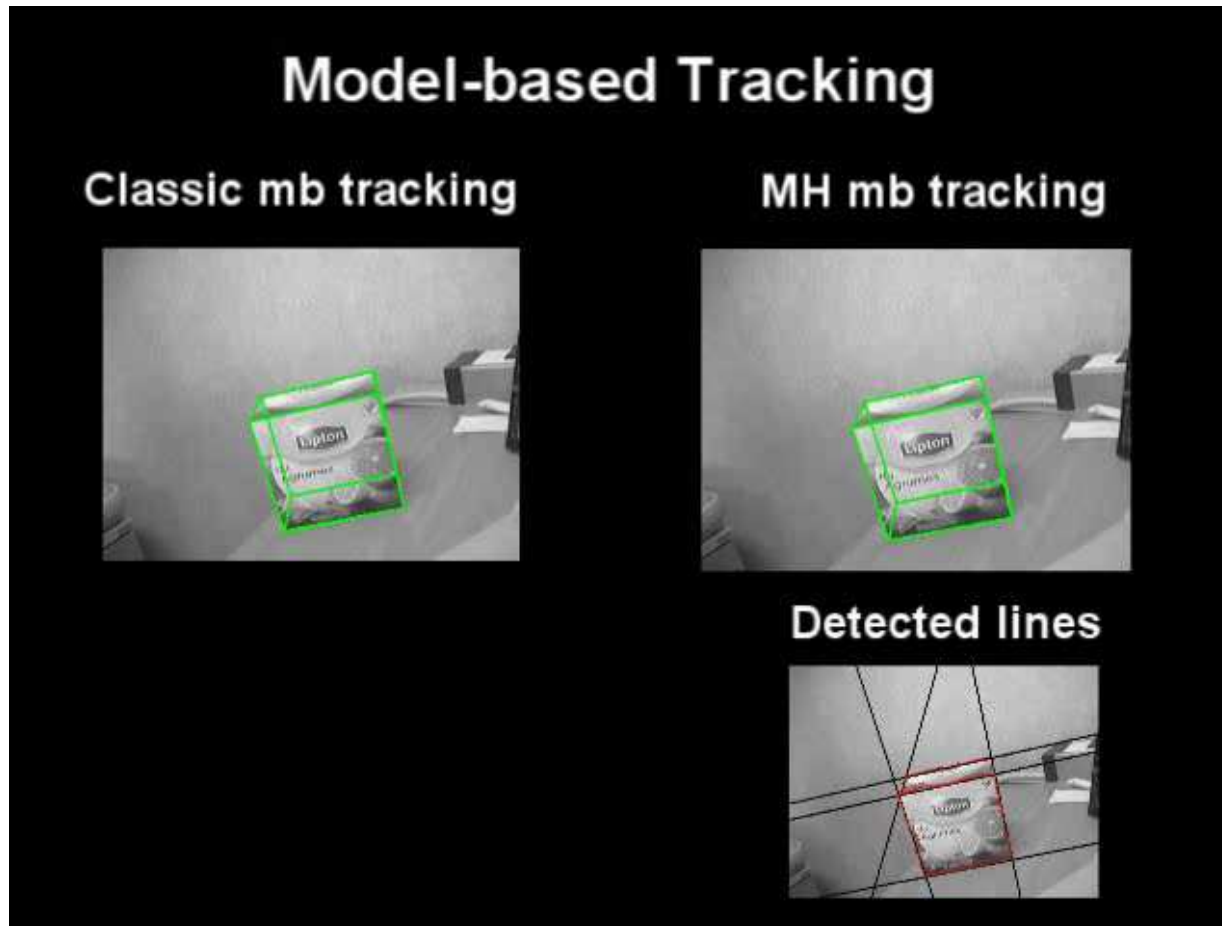
# Exemples

➤ Simulation

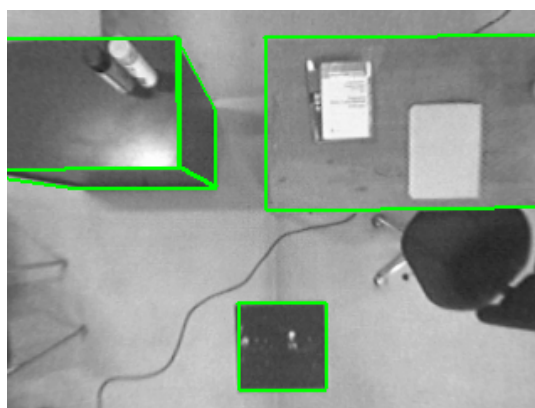
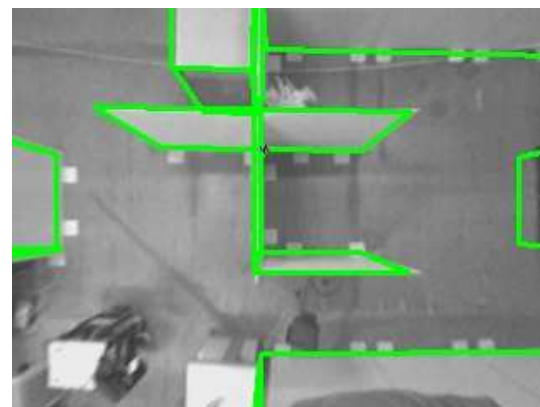
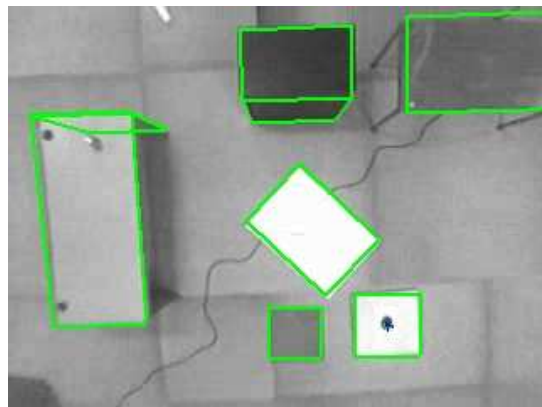


# Exemples

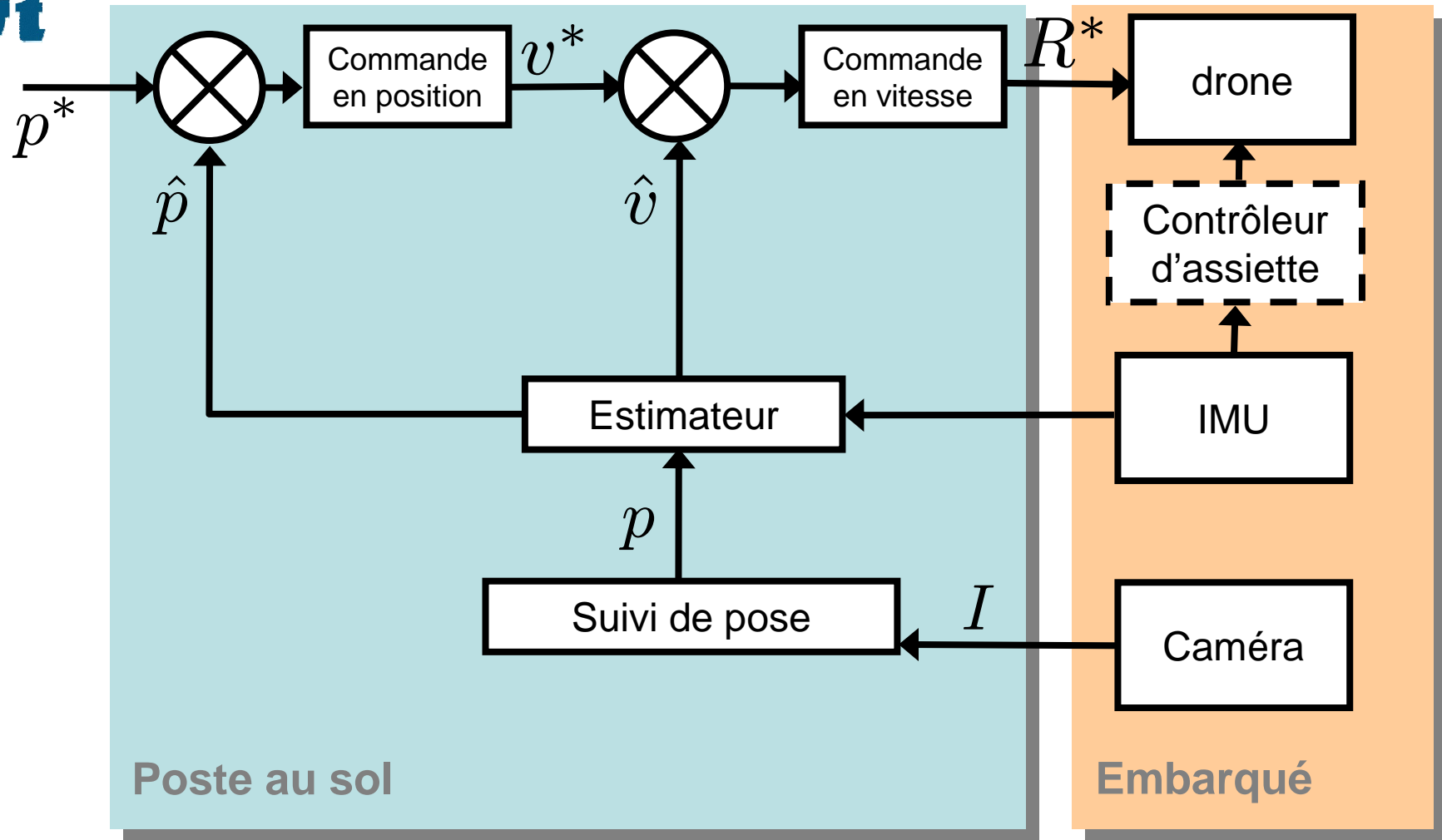
➤ Séquence réelle



# Scènes complexes



## Estimation de vitesse



# Modèle du quadri-rotor

## ➤ Système non linéaire sous actionné

## ➤ Repères utilisés

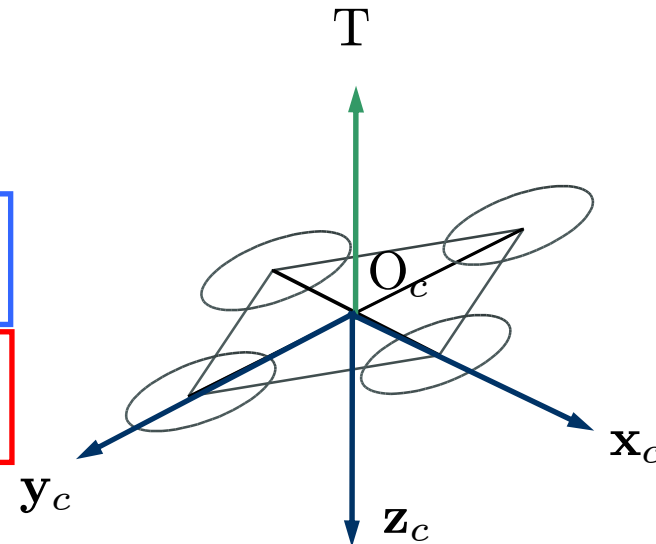
- ✓ I : Repère inertiel (terrestre)
- ✓ C : Repère fixé au centre de masse du véhicule (supposé coïncider avec la caméra)

Translation

$$\begin{cases} \dot{\mathbf{p}} = \mathbf{v} \\ m\dot{\mathbf{v}} = T\mathbf{R}\mathbf{e}_z - f\mathbf{v}^2\mathbf{u}_v + m\mathbf{g}\mathbf{e}_z \end{cases}$$

Rotation

$$\begin{cases} \dot{\mathbf{R}} = [\boldsymbol{\Omega}]_{\times} \\ \mathbf{I}\dot{\boldsymbol{\Omega}} = -\boldsymbol{\Omega} \times \mathbf{I}\boldsymbol{\Omega} + \boldsymbol{\Gamma} \end{cases}$$

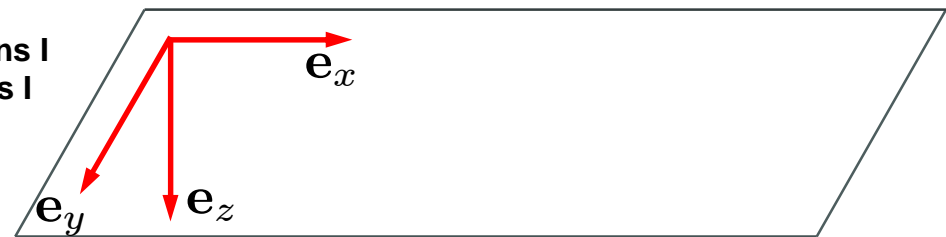


## ➤ Etat :

- ✓  $\mathbf{p}$  : position du centre de masse dans I
- ✓  $\mathbf{v}$  : vitesse du centre de masse dans I
- ✓  $\mathbf{R}$  : rotation de C vers I
- ✓  $\boldsymbol{\Omega}$  : vitesse de rotation dans C

## ➤ Entrées :

- ✓  $T$  : Poussée dans C
- ✓  $\boldsymbol{\Gamma}$  : Couple dans C



## Estimation de vitesse

➤ **EKF (Extended Kalman Filter)**

✓ Etat :  $(\mathbf{p}^\top \mathbf{v}^\top \mathbf{a}^\top)^\top$

$$\dot{\mathbf{p}} = \mathbf{v}$$

$$m\dot{\mathbf{v}} = T\mathbf{R}\mathbf{e}_z - f\mathbf{v}^2\mathbf{u}_v + mg\mathbf{e}_z$$

➤ **Hypothèses simplificatrices :**

- ✓ Vitesses de translations en x et y découplées
- ✓ Petits angles
- ✓ Coefficient de frottement constant
- ✓ Poussée constante

➤ **Modèle d'évolution :**

$$a_x^{(t+\delta t)} = \frac{T}{m}\phi^{(t-\tau)} - \text{sign}(v_x)\frac{f}{m}v_x^2 + n_{ax}$$

$$a_y^{(t+\delta t)} = \frac{T}{m}\theta^{(t-\tau)} - \text{sign}(v_y)\frac{f}{m}v_y^2 + n_{ay}$$

$$a_z^{(t+\delta t)} = a_z^{(t)} + n_{az}$$

$$\mathbf{n}_a = \mathcal{N}(0, \mathbf{Q}_a)$$

$$\begin{cases} v^{(t+\delta t)} = v^{(t)} + a^{(t+\delta t)}\delta t \\ p^{(t+\delta t)} = p^{(t)} + v^{(t+\delta t)}\delta t \end{cases}$$



## Estimation de vitesse

➤  $\mathcal{T}$  ,  $\alpha = \frac{T}{m}$  ,  $\beta = \frac{f}{m}$  appris (ici par un algorithme génétique)

➤ EKF :

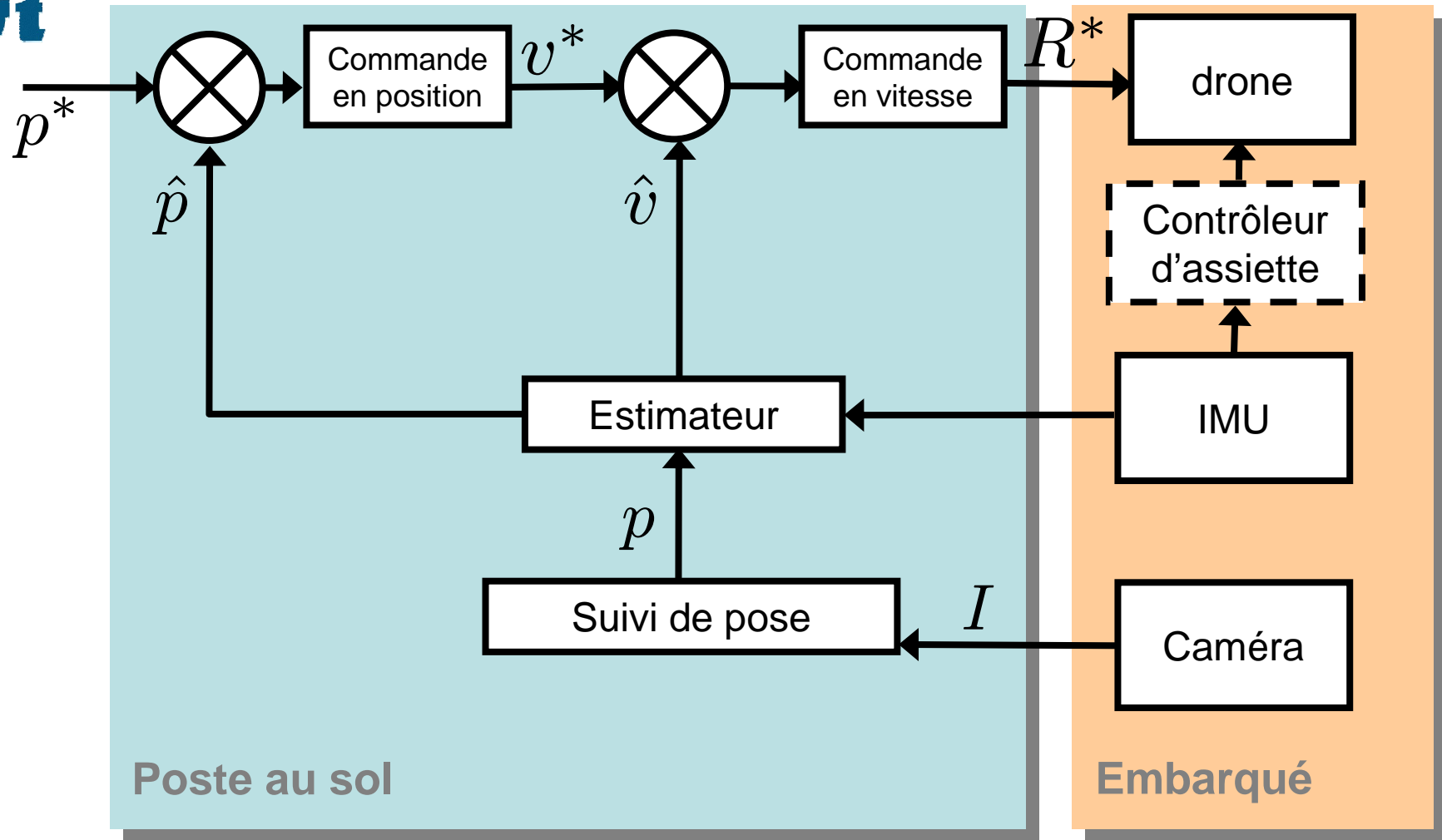
$$\mathbf{J}_x = \begin{bmatrix} \mathbf{I} & \delta t \mathbf{I} & \mathbf{0} \\ \mathbf{0} & \mathbf{I} & \delta t \mathbf{I} \\ \mathbf{0} & -\text{sign}(v) 2\beta v a & \mathbf{0} \end{bmatrix}$$

$$\mathbf{P}_{(t+\delta t)|t} = \mathbf{J}_x \mathbf{P}_{t|t} \mathbf{J}_x^T + \mathbf{J}_n \mathbf{Q} \mathbf{J}_n^T$$

➤ Observation : position obtenue par suivi visuel

$$\mathbf{X}_{t+\delta t} = \begin{bmatrix} \mathbf{I} \\ \mathbf{0} \\ \mathbf{0} \end{bmatrix} [\hat{\mathbf{p}}]$$

## Commande



## Commande

- **Lacet**  $\Omega_z^* = -K_p \psi (\psi^* - \psi)$ 
  - ✓ Vitesse de rotation contrôlée en embarqué à l'aide des gyro

- **Translation**

- ✓ Commande hiérarchique : PI en vitesse, P en position

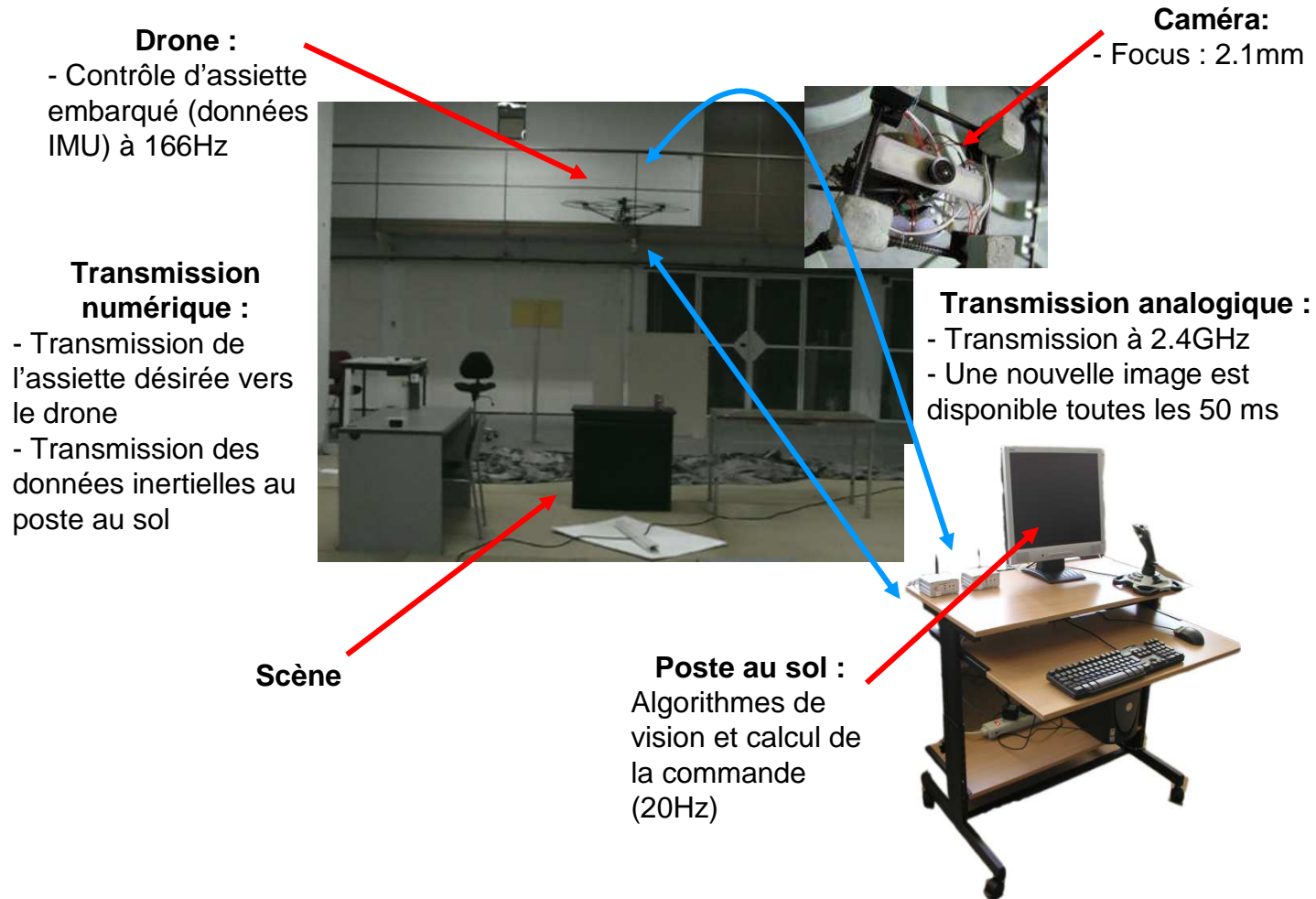
$$\epsilon_p = \mathbf{p}^* - \mathbf{p}$$

Consigne d'assiette :

$$K_{Pv}(K_P \epsilon_p - \mathbf{v}) + K_{Iv} \int (K_F \epsilon_p - \mathbf{v})$$

Assiette contrôlée en embarqué

# Dispositif experimental

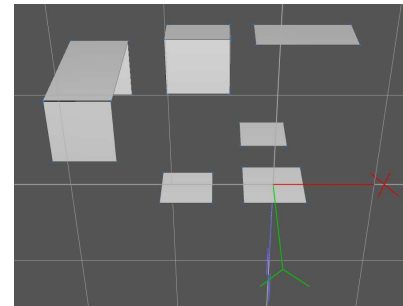


## Dispositif expérimental

- Scène : objets plans / objets 3D

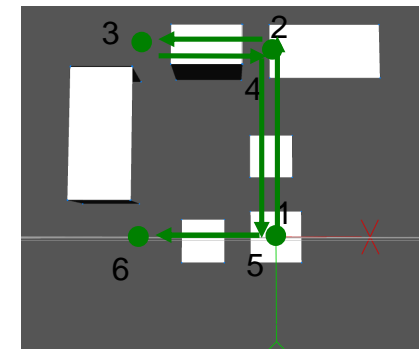


Scène



Modèle

- Tâche : points de passage successifs (différentes consignes de position)
- La cible est utilisée uniquement pour l'initialisation





## Résultats expérimentaux

# 3D Model-Based Tracking for UAV Position Control

C. Teulière L. Eck E. Marchand N. Guénard

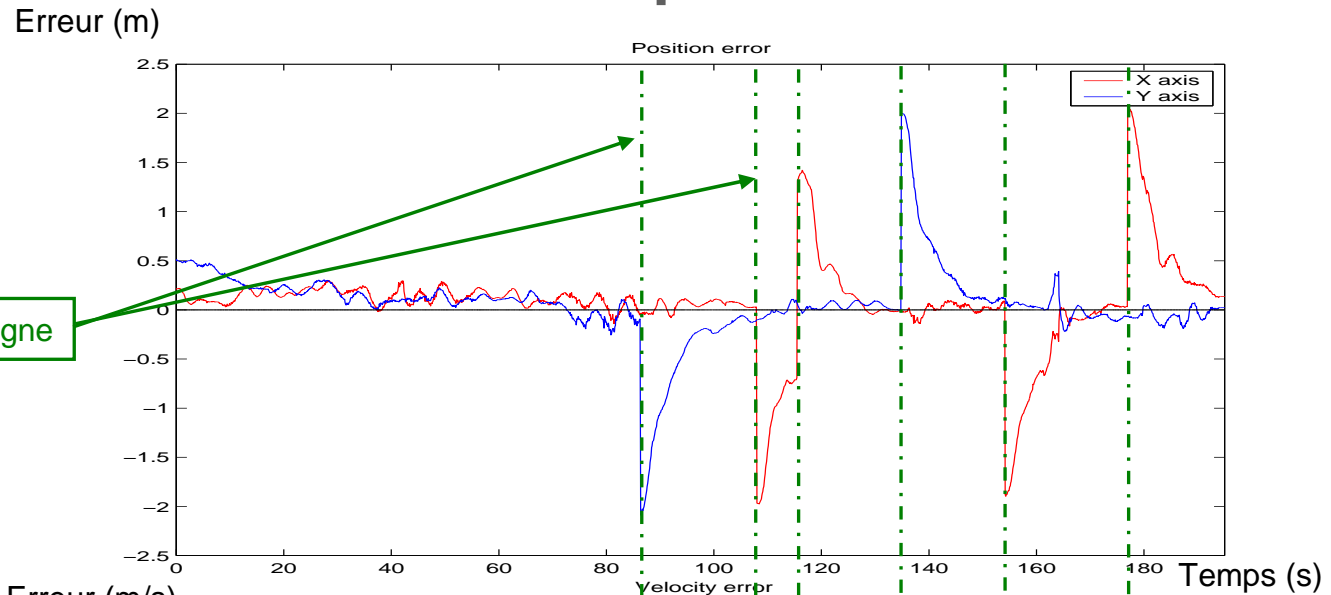
CEA LIST Interactive Robotics Unit

IRISA/INRIA Rennes-Bretagne Atlantique  
Lagadic Project  
<http://www.irisa.fr/lagadic>

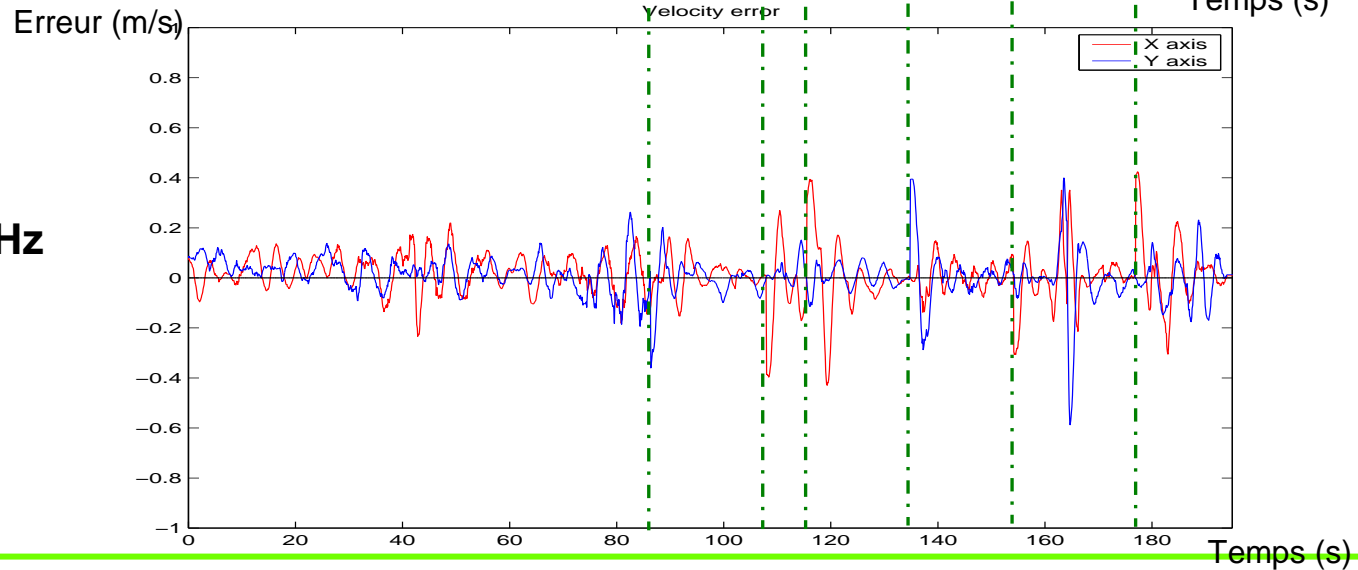




# Résultats expérimentaux



Changements de consigne



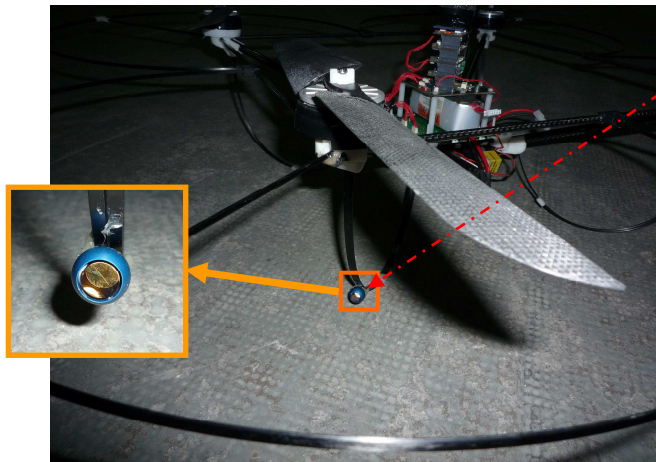
Fréquence : 20 Hz



## Résultats expérimentaux

### ➤ Mesure de la précision

- ✓ « Vérité terrain » fournie par un tracker Laser Leica
- ✓ Fréquence d'acquisition : 1000Hz
- ✓ Mesure au micromètre

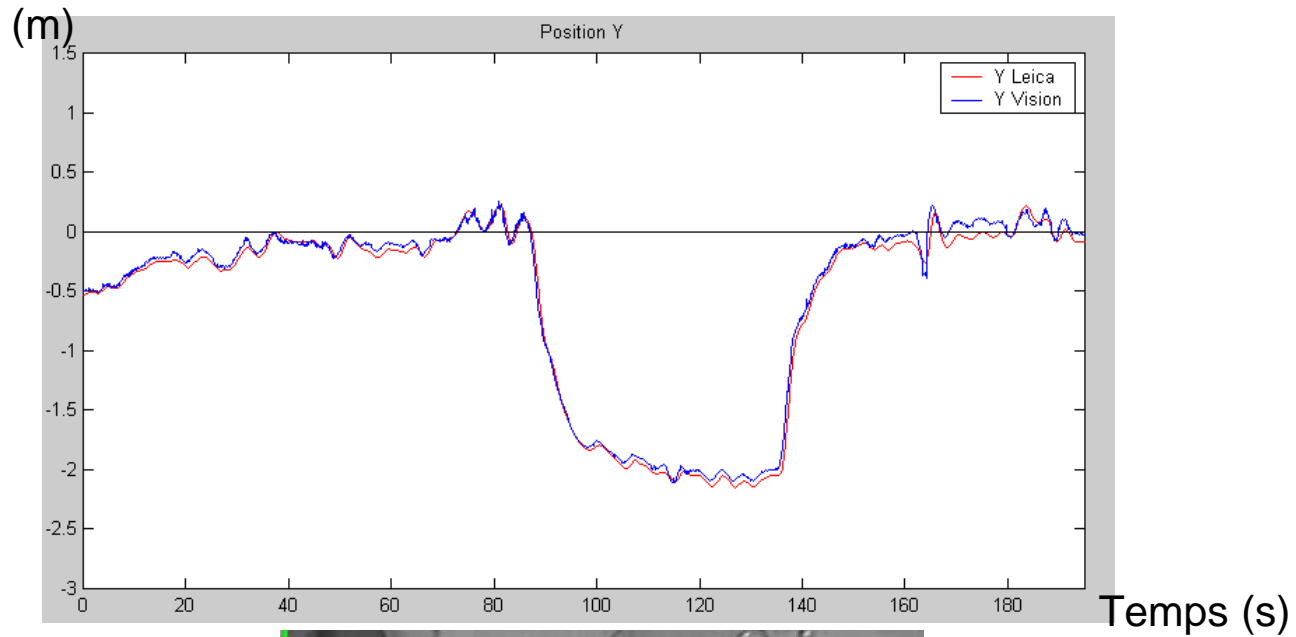


Miroir

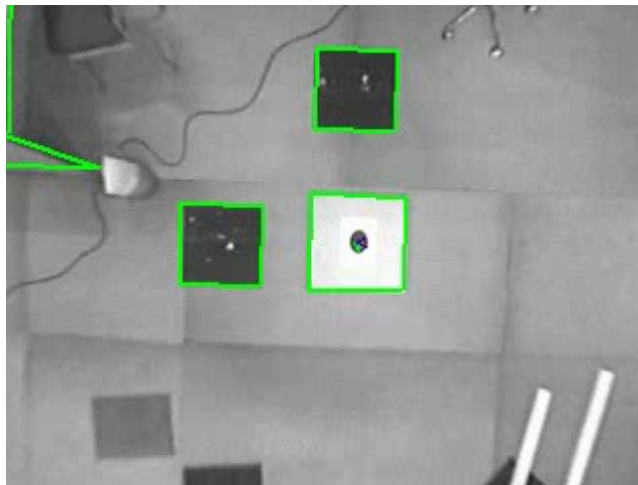




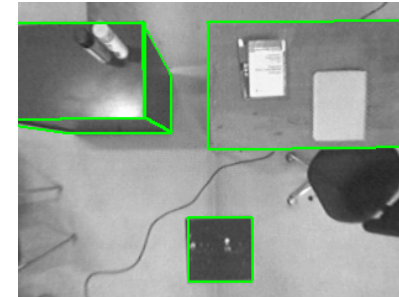
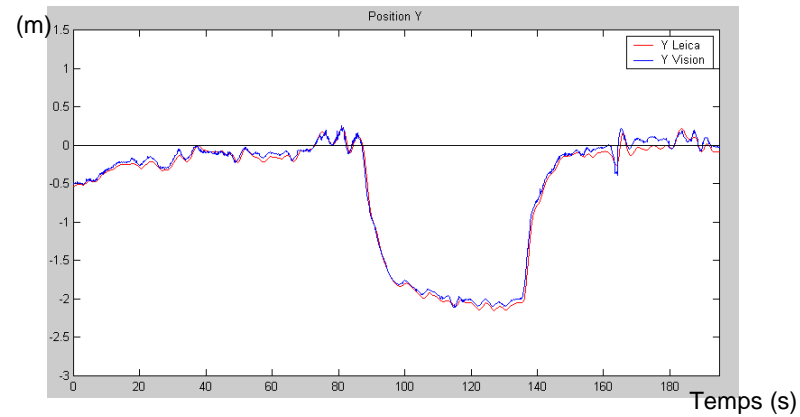
# Résultats expérimentaux



Vue caméra

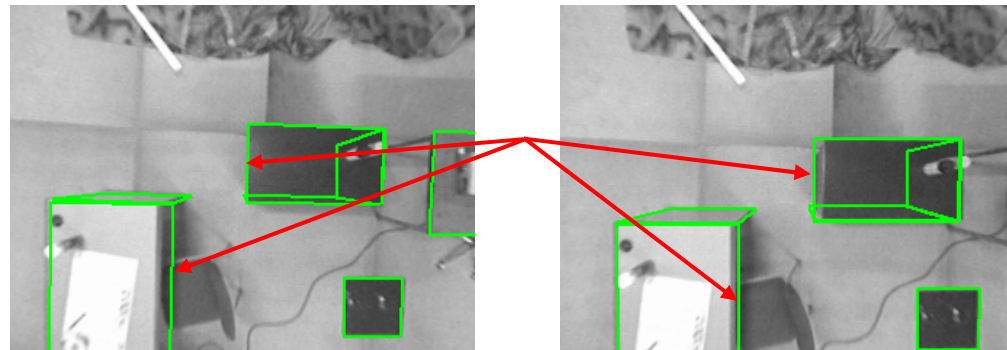


## Résultats expérimentaux



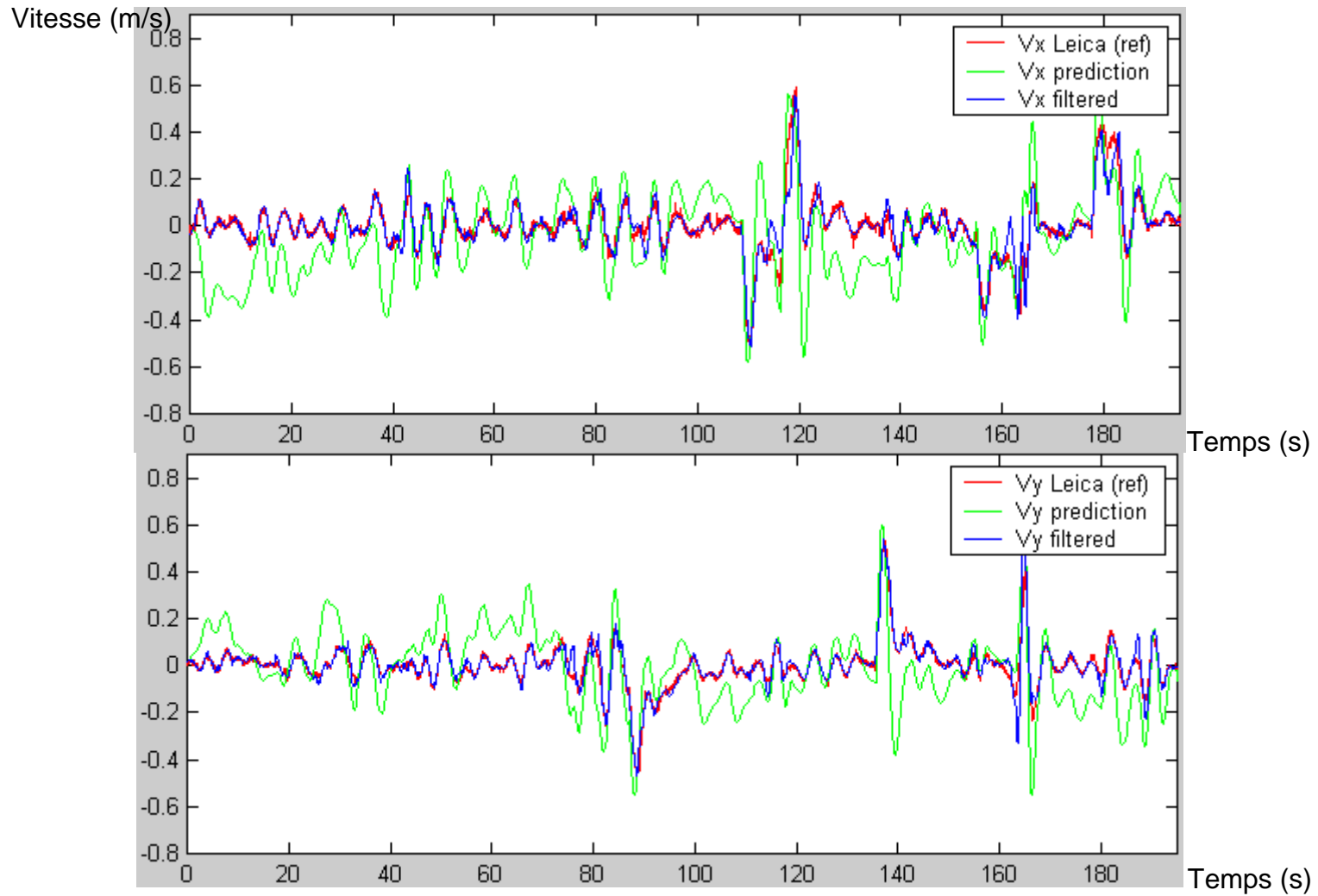
### ➤ Bonne précision

- ✓ Erreur max : 10cm
- ✓ Due à l'imprécision du modèle :





## Résultats expérimentaux : estimation de vitesse



## Conclusion

- **Suivi basé modèle :**
  - ✓ Pas à la mode
  - ✓ Mais à ne pas négliger
    - Précision
    - Robustesse (améliorée par l'approche multi-hypothèse)
    - Adapté à des environnements structurés
  
- **La fusion avec les données inertielles permet une bonne estimation de vitesse**

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cea

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**list**

?



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cea

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**list**



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cea

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**list**



# Publications

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- [1] C. Teulière, E. Marchand, L. Eck, “A combination of particle filtering and deterministic approaches for multiple kernel tracking”, *IEEE International Conference on Robotics and Automation*, 2009.
- [2] C. Teulière, “Approche multi-noyaux pour le suivi temps-réel d’objet mobile”, *Congrès des jeunes chercheurs en vision par ordinateur*, 2009.





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cea

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list



# Modèle du quadri-rotor

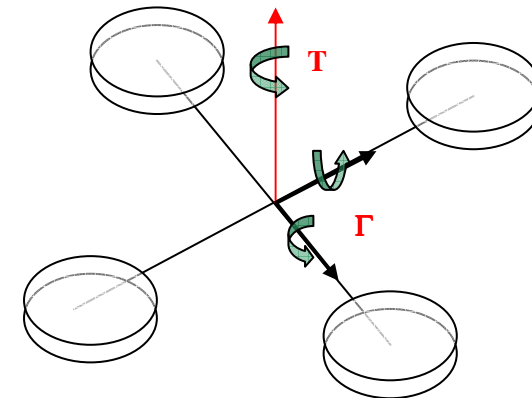
- The system is nonlinear and under actuated.
- Definition of used frames.
  - ✓ I : Inertial frame attached to the earth
  - ✓ B : body-fixed frame attached to the vehicle's center of mass.

- Vehicle state:

- ✓  $\xi$ : position of the center of mass in I
- ✓  $v$ : speed of the center of mass in I
- ✓  $R$ : orientation matrix from B to I
- ✓  $\Omega$ : rotational velocity in B

- Inputs:

- ✓  $T$ : Global thrust in B
- ✓  $\Gamma$ : Control torque in B



- Dynamic Model used :

$$\begin{aligned}
 & \dot{\xi} = v \\
 & m\dot{v} = -TRe_3 + mge_3 + \Delta \text{ forces} \\
 & \epsilon \dot{R} = R\Omega_{\times}, \\
 & \epsilon \dot{I}\Omega = -\Omega \times I\Omega + \Gamma.
 \end{aligned}$$

$F=f(T,R)$

Translational dynamics → (points to the first two equations)

Rotational Dynamics → (points to the last two equations)

Constant forces → (points to the  $mge_3$  term)

Already controlled → (points to the  $\Gamma$  term in the rotational equation)

High gain controller → (points to the rotational dynamics equation)

$$\begin{aligned}
 & = v \\
 & = F + \Delta
 \end{aligned}$$

## Particle filtering approach

$$\mathbf{x} = (v, \omega)^T$$

- Prediction step: Evolution of the particles according to a motion model
- **State:** (canonical exponential coordinates)
- **Set of particles: sampling of the pose distribution**
- Update step: For each particle  $\mathbf{x}_k$ 
  - Projection of the model according to the pose parametrised by  $\mathbf{x}_k$
  - Sampling of the edges
  - Tracking of the points
  - Distance computation
- ➡ Deduce particle's weight  $w^{(i)} \propto p(\mathbf{z} | \mathbf{x} = x^{(i)})$
- Resampling

## Precaution when filtering on SE(3)

➤  $\mathbf{W}^{\mathbf{M}}_{\text{noise}} = \exp(\sum_{i=1}^6 \alpha_i \mathbf{G}_i)$ ,  $\alpha \sim N(0, \sigma^2 \mathbf{I}_6)$  **on a Lie group**

- ✓ Gaussian distributions ?
- ✓ On the canonical exponential coordinates, and then exponential map...

$$\bar{R} = \sum_{n=1}^N \frac{R_n}{N} \quad \text{It con:} \quad R = \begin{cases} VU^\top, & \text{if } \det(\bar{R}^\top) > 0, \\ VHU^\top, & \text{otherwise,} \end{cases}$$

- ✓ Usually the weighted mean... No meaning here
- **Where**  $\bar{R}^\top = U\Sigma V^\top$  **Singular Value**  
 ✓ Mean rotation  $H = \text{diag}[1, 1, -1]$  **Decomposition** on SO(3)

➤ Evolution  
model

$$X_{pred} = e^{\xi t} \cdot X$$

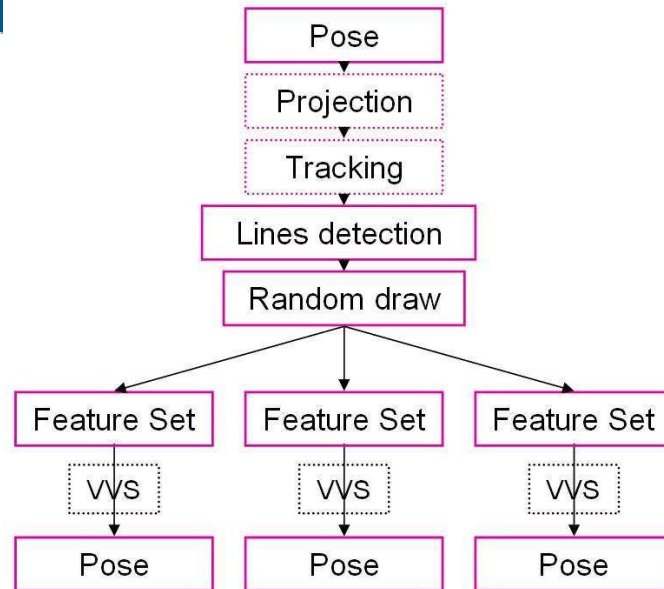
$$X_{pred} = M_{noise} \cdot e^{\xi t} \cdot X$$



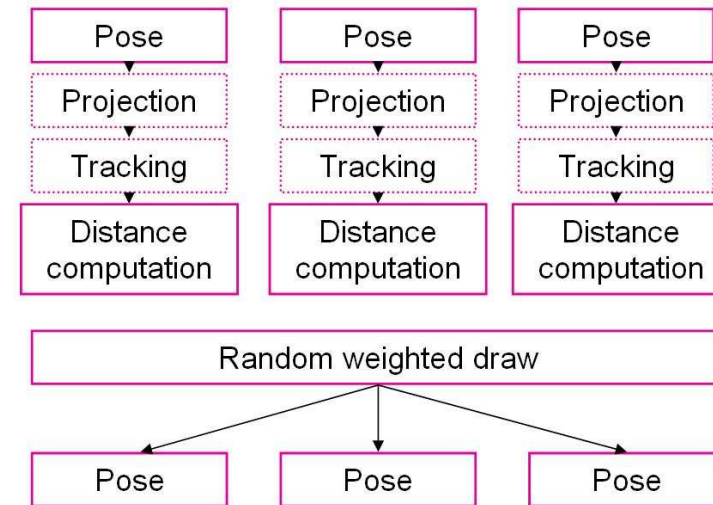
$$\xi = \begin{bmatrix} [\omega]_{\times} & v \\ 0 & 0 \end{bmatrix}$$

- Precision of the inertial measurements of the UAV?
- No video yet

## Comparison... toward a combination



### ➤ Particle filtering



Time consuming... ☹

### ➤ Work in progress:

- ✓ Combine Top-down / Bottom-up informations?
- ✓ Use a small set of hypothesis...