# UNCOOPERATIVE OBJECTS POSE, MOTION AND INERTIA TENSOR ESTIMATION VIA STEREOVISION

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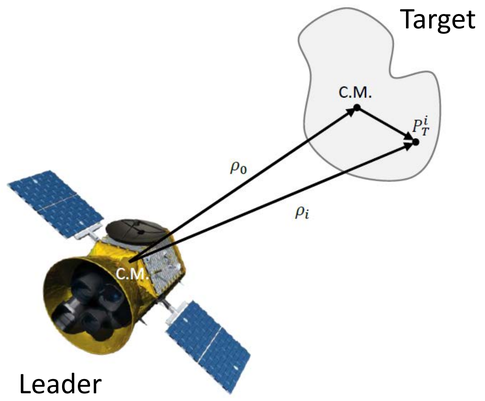
## *MAIN GOAL - STATE ESTIMATION*

**Leader – Target representation**



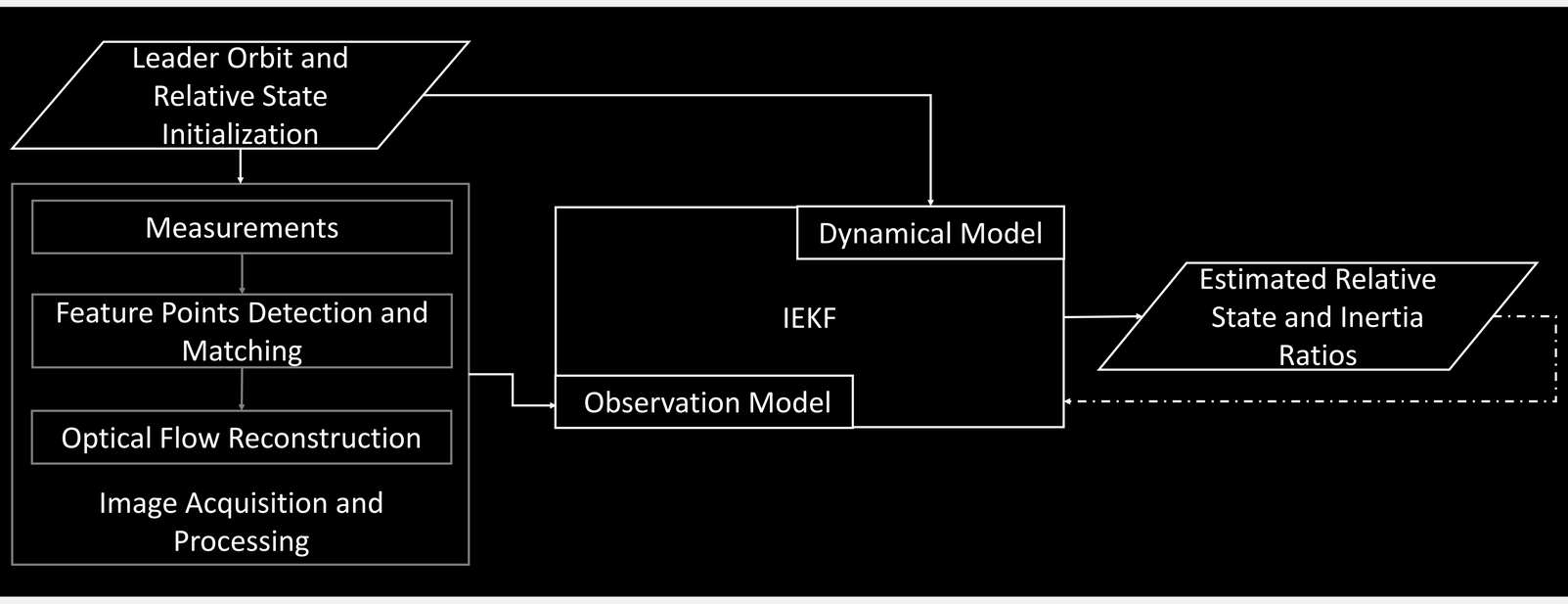

**STATE, MOTION AND INERTIA ESTIMATION**

**UNKNOWN AND UNCOOPERATIVE OBJECT**
- No a-priori available information
- No target identifiers

**REAL TIME ESTIMATION ALGORITHM**
- Accuracy and generality
- Computational efficiency

***SOLUTION***
- Two cameras in stereovision configuration
- Iterated Extended Kalman Filter
- Estimation of the inertia ratios

## *PROPOSED SOLUTION*




**DYNAMICAL MODEL**
- Non-linear relative translational motion model
- Combination of the Euler equations for the relative rotational motion
- Torque free motion

**OBSERVATION MODEL**
- Pinhole camera model
- Image velocity as approximation of the optical flow
- Disparity computation

Pseudo-measurement constraint for the inertia ratios estimation

## *NUMERICAL SIMULATIONS*

- ***Inertia Matrix Parametrization***

$$I_T = \begin{bmatrix} e^{k1} & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & e^{-k2} \end{bmatrix} \qquad k_1 = \log\frac{I_{11}}{I_{22}} \quad k_2 = \log\frac{I_{22}}{I_{33}}$$

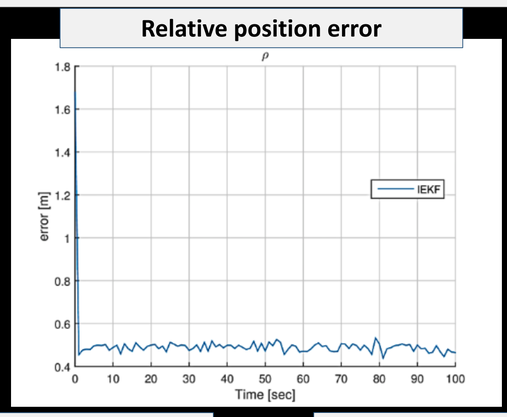
- ***Pseudo-measurement constraint***

$0 = I_T\dot{\omega}_T + \omega_T \times I_T\omega_T$

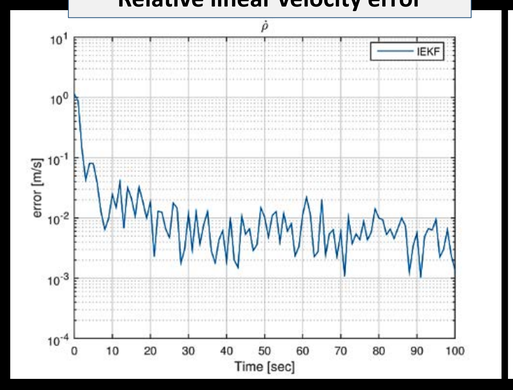
($\dot{\omega}_T$ computed with numerical differentiation method)

| State Initial Conditions | | |
|---|---|---|
| $\boldsymbol{\rho_0}$ | [10, 60, 10] | m |
| $\dot{\boldsymbol{\rho}}_{\boldsymbol{0}}$ | [0.01, -0.0225, -0.01] | m/s |
| $\boldsymbol{\omega_0}$ | [-0.1, -0.1, 0.034] | deg/s |
| $\boldsymbol{q_0}$ | [0, 0, 0, 1] | - |
| $\boldsymbol{k_1}$ | log(0.9231) | - |
| $\boldsymbol{k_2}$ | log(0.782) | - |

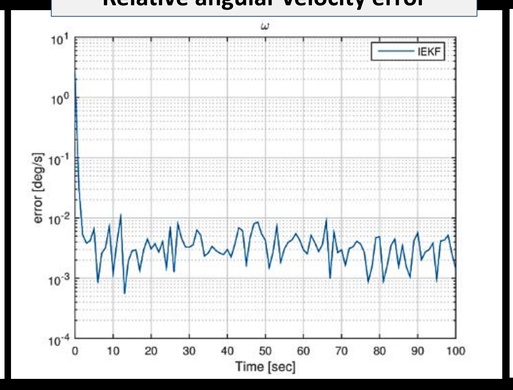
**Relative position error**



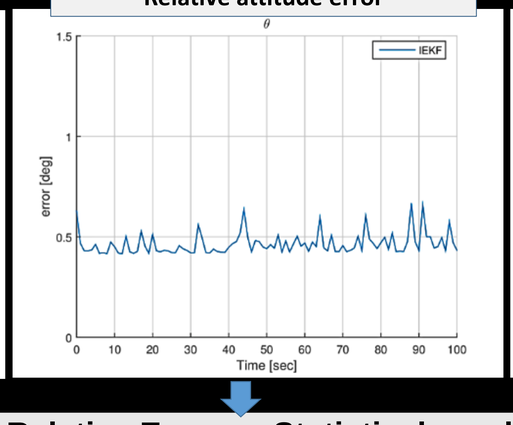

**Relative linear velocity error**



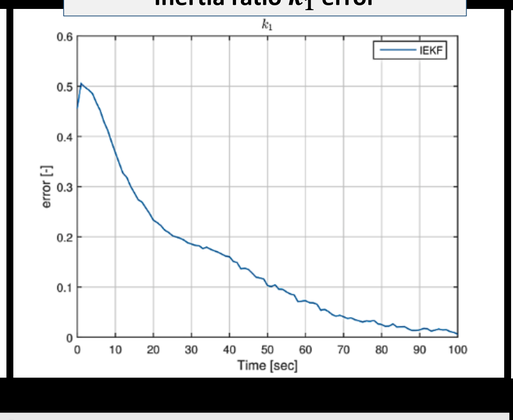

**Relative angular velocity error**



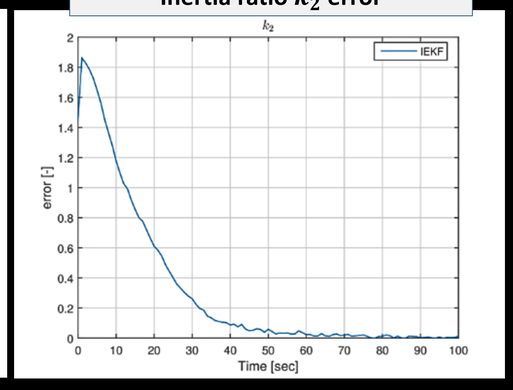

**Relative attitude error**




**Inertia ratio $k_1$ error**




**Inertia ratio $k_2$ error**




| Relative Errors – Statistical results | | | | | | |
|---|---|---|---|---|---|---|
| **Percentiles** | $\boldsymbol{\rho_0}$[m] | $\dot{\boldsymbol{\rho}}_{\boldsymbol{0}}[m/s]$ | $\boldsymbol{\omega_0}[deg/s]$ | $\boldsymbol{\theta}[deg]$ | $\boldsymbol{k_1}[-]$ | $\boldsymbol{k_2}[-]$ |
| 50 | 0.51 | 0.0062 | 0.0035 | 0.49 | 0.067 | 0.037 |
| 70 | 0.64 | 0.0067 | 0.0036 | 0.61 | 0.13 | 0.051 |
| 90 | 0.73 | 0.0073 | 0.0039 | 0.77 | 0.24 | 0.23 |
| 100 | 0.9 | 0.011 | 0.0043 | 0.87 | 0.53 | 0.23 |

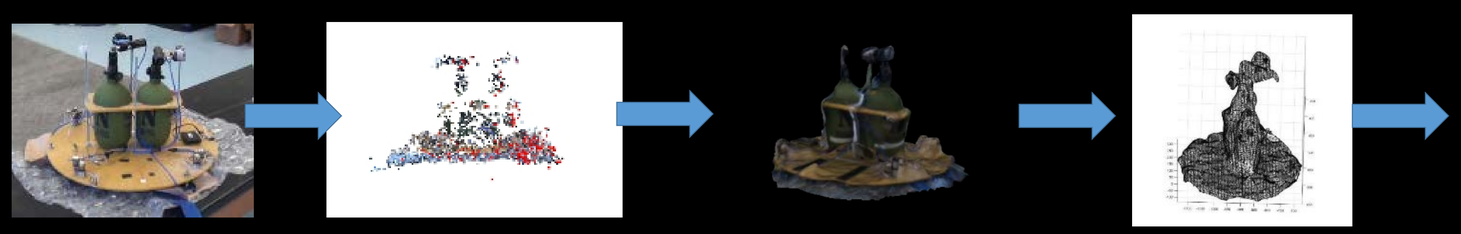
Results for 100 runs

- ***No pseudo-constraint – High relative angular velocity***

| State Initial Conditions | | |
|---|---|---|
| $\boldsymbol{\rho_0}$ | [10, 60, 10] | m |
| $\dot{\boldsymbol{\rho}}_{\boldsymbol{0}}$ | [0.01, -0.0225, -0.01] | m/s |
| $\boldsymbol{\omega_0}$ | *[-1, -1, 0.934]* | deg/s |
| $\boldsymbol{q_0}$ | [0, 0, 0, 1] | - |
| $\boldsymbol{k_1}$ | log(0.9231) | - |
| $\boldsymbol{k_2}$ | log(0.782) | - |

| Relative Errors – Statistical results | | | | | | |
|---|---|---|---|---|---|---|
| **Percentiles** | $\boldsymbol{\rho_0}$[m] | $\dot{\boldsymbol{\rho}}_{\boldsymbol{0}}[m/s]$ | $\boldsymbol{\omega_0}[deg/s]$ | $\boldsymbol{\theta}[deg]$ | $\boldsymbol{k_1}[-]$ | $\boldsymbol{k_2}[-]$ |
| 50 | 0.53 | 0.01 | 0.012 | 1.8 | 0.035 | 0.021 |
| 70 | 0.64 | 0.013 | 0.013 | 2 | 0.043 | 0.024 |
| 90 | 0.76 | 0.017 | 0.014 | 2.2 | 0.069 | 0.032 |
| 100 | 0.94 | 0.02 | 0.016 | 2.5 | 0.15 | 0.043 |

- **A POSTERIORI IMAGE PROCESSING FOR COMPLETE INERTIA MATRIX RECONSTRUCTION**



Video to Images | Point Cloud [Visual SFM] | Mesh [MeshLab] | Inertia Components

Experimental Result (constant density $\rho = 1\frac{g}{cm^3}$)

**Exact value**

$$I = \begin{bmatrix} 675.65 & 0 & 0 \\ 0 & 787 & 0 \\ 0 & 0 & 819.33 \end{bmatrix} kg\ cm^2$$

**Estimated value**

$$I = \begin{bmatrix} 795.49 & 0 & 0 \\ 0 & 855.07 & 0 \\ 0 & 0 & 978.07 \end{bmatrix} kg\ cm^2$$

The exact value is obtained with a CAD model, imposing the same constant density value

## *FINAL HIGHLIGHTS*

The developed algorithm performs the relative state estimation with no restrictive assumption. It outperforms the recent results in the literature. It demonstrate that it is possible to estimate the inertia ratios, in torque free motion, with different values of the relative angular velocity, with or without pseudo-constraint. The filtering procedure allows for a computationally efficient implementation. Finally, a rough inertia matrix estimation is obtained with a video-processing procedure.