Visual Motion Observer for Panoramic Camera

FL seminar

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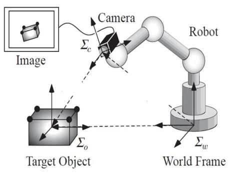
Outline

Introduction

Vision Based Control

- Robots need information from sensors to operate autonomously in dynamical environments.
- Visual information is suited to recognize unknown surroundings.



Visual Motion Observer

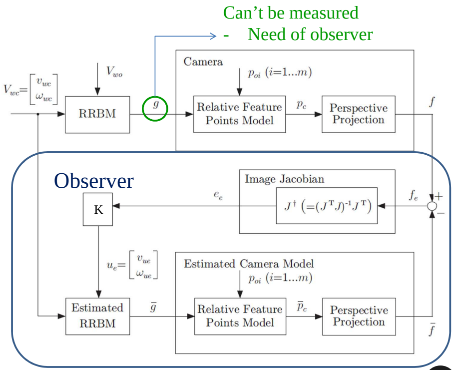
- Estimate Relative Rigid Body Motion based only on image information

Outline

Visual Motion Observer

Goal

- Estimate Relative Rigid Body Motion based only on image information



Theory

- Estimation error
  $e_e = 0$ iff $g = \bar{g}$ [2]

Outline

Relative Rigid Body Motion [1]

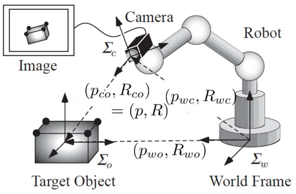
Pose

$g_{ab} = (p_{ab}, R_{ab})$

Pose of body *b* relative to body *a*

Position Vector : $p_{ab} \in R^3$

Rotation Matrix : $R_{ab} \in R^6$



Body Velocity

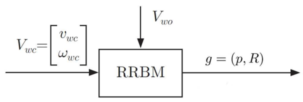
$$V_{ab} = \begin{bmatrix} v_{ab} \\ \omega_{ab} \end{bmatrix} \in R^6$$

linear velocity : $v_{ab} \in R^3$

angular velocity : $\omega_{ab} \in R^3$

Equations for RRBM-model

$$p = R_{wc}^T (p_{wo} - p_{wc})$$
$$R = R_{wc}^T R_{wo}$$
$$\dot{p} = -v_{wc} + \hat{p}\omega_{wc} + R v_{wo}$$
$$\dot{R} = -\hat{\omega}_{wc} R + R\hat{\omega}_{wo}$$



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- Visual Motion Observer
  - Relative Rigid Body Motion
  - Camera Models and Image Jacobian
    - Pinhole Camera
    - Panoramic Camera
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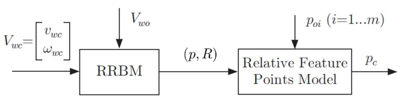
- Conclusions and Future Work

Relative Feature Points Model [2]

Relative Feature Points Model

Transformation of the feature points from the object frame to the camera frame



$$p_{oi} = \begin{bmatrix} x_{oi} \\ y_{oi} \\ z_{oi} \end{bmatrix},$$

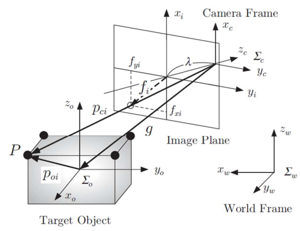
$$p_{ci} = \begin{bmatrix} x_{ci} \\ y_{ci} \\ z_{ci} \end{bmatrix} = g p_{oi} = R p_{oi} + p \qquad p_c = \begin{bmatrix} p_{c1} \\ \vdots \\ p_{cm} \end{bmatrix}$$

Perspective Projection for Pinhole Camera [2]

Transform feature points from 3D to 2D in the Image Plane

$$f_i = \frac{\lambda}{z_{ci}} \begin{bmatrix} x_{ci} \\ y_{ci} \end{bmatrix}, \quad f = \begin{bmatrix} f_i \\ \vdots \\ f_m \end{bmatrix}$$

λ is the focal length of the camera



Pinhole Camera Model [2]

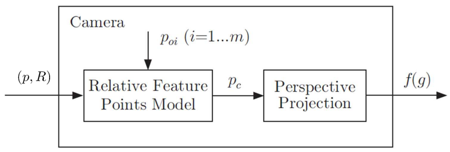


Image Jacobian for Pinhole Camera [2]

Theory

Estimation Error

$e_e = J^{\dagger} f_e$ [2]

$e_e \in R^6$

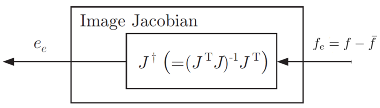


Image Jacobian for the Pinhole Camera

$$J_i := \begin{bmatrix} \frac{\lambda}{\bar{z}_{ci}} & 0 & -\frac{\lambda \bar{x}_{ci}}{\bar{z}_{ci}^2} \\ 0 & \frac{\lambda}{\bar{z}_{ci}} & -\frac{\lambda \bar{y}_{ci}}{\bar{z}_{ci}^2} \end{bmatrix} \begin{bmatrix} I & -(\bar{R} p_{oi})^{\wedge} \end{bmatrix}$$

$$J = \begin{bmatrix} J_1 \\ \vdots \\ J_m \end{bmatrix} \begin{bmatrix} \bar{R} & 0 \\ 0 & \bar{R} \end{bmatrix}$$

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Perspective Projection for Panoramic Camera [3]

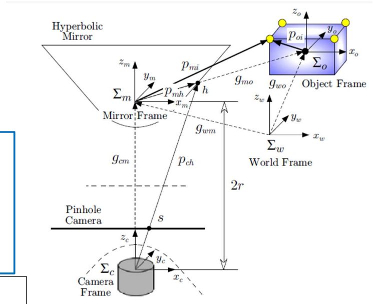
$$f_i = \frac{\lambda\alpha(p_{mi})}{2r+\alpha(p_{mi})z_{mi}}\begin{bmatrix}x_{mi}\\ y_{mi}\end{bmatrix},$$

$$f = \begin{bmatrix}f_i\\ \vdots\\ f_n\end{bmatrix}$$

$$\alpha(p_{mi}) = \frac{b^2(rz_{mi}+a\|p_{mi}\|)}{a^2x_{mi}^2+a^2y_{mi}^2-b^2z_{mi}^2},$$

$$\frac{(z_{mh}+r)^2}{a^2}-\frac{x_{mh}^2+y_{mh}^2}{b^2}=1,$$

$$r=\sqrt{a^2+b^2}$$



Panoramic Camera Model [3]

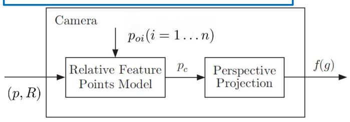


Image Jacobian for Panoramic Camera [3]

$$J_i := \begin{bmatrix}\frac{\partial f_i}{\partial x_{mi}}|_{p_{mi}=\bar{p}_{mi}} & \frac{\partial f_i}{\partial y_{mi}}|_{p_{mi}=\bar{p}_{mi}} & \frac{\partial f_i}{\partial z_{mi}}|_{p_{mi}=\bar{p}_{mi}}\end{bmatrix}\begin{bmatrix}I & -(\bar{R}p_{oi})^\wedge\end{bmatrix}$$

$$J = \begin{bmatrix}J_1\\ \vdots\\ J_n\end{bmatrix}\begin{bmatrix}\bar{R} & 0\\ 0 & \bar{R}\end{bmatrix}$$

$$\frac{\partial f_i}{\partial x_{mi}} = \frac{2r\lambda\alpha_x(p_{mi})}{(2r+\alpha(p_{mi})z_{mi})^2}\begin{bmatrix}x_{mi}\\ y_{mi}\end{bmatrix}+\frac{\lambda\alpha(p_{mi})}{2r+\alpha(p_{mi})z_{mi}}\begin{bmatrix}1\\ 0\end{bmatrix}$$

$$\frac{\partial f_i}{\partial y_{mi}} = \frac{2r\lambda\alpha_y(p_{mi})}{(2r+\alpha(p_{mi})z_{mi})^2}\begin{bmatrix}x_{mi}\\ y_{mi}\end{bmatrix}+\frac{\lambda\alpha(p_{mi})}{2r+\alpha(p_{mi})z_{mi}}\begin{bmatrix}0\\ 1\end{bmatrix}$$

$$\frac{\partial f_i}{\partial z_{mi}} = \frac{2r\lambda\alpha_z(p_{mi})}{(2r+\alpha(p_{mi})z_{mi})^2}\begin{bmatrix}x_{mi}\\ y_{mi}\end{bmatrix}-\frac{\lambda\alpha^2(p_{mi})}{(2r+\alpha(p_{mi})z_{mi})^2}\begin{bmatrix}x_{mi}\\ y_{mi}\end{bmatrix}$$

$$\left(\alpha_x(p_{mi})=\frac{\partial\alpha(p_{mi})}{\partial x_{mi}},\alpha_y(p_{mi})=\frac{\partial\alpha(p_{mi})}{\partial y_{mi}},\alpha_z(p_{mi})=\frac{\partial\alpha(p_{mi})}{\partial z_{mi}}\right)$$

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Simulation Settings

Relative Pose

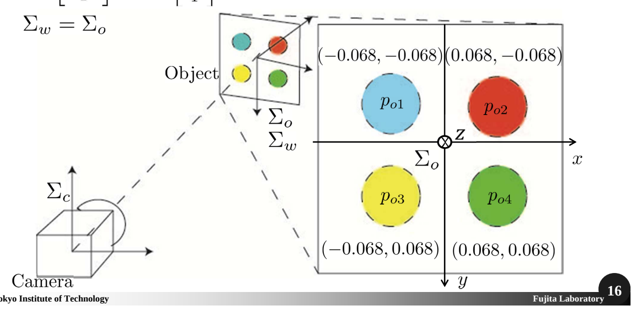
$g=(p,R)$ $\quad R=e^{\hat{\xi}_{co}\theta_{co}}$

$$p=\begin{bmatrix}0.2\\ 0.2\\ 1\end{bmatrix},\ \xi_{co}=\begin{bmatrix}0\\ 0\\ 1\end{bmatrix},\theta_{co}=\pi/8$$

$\Sigma_w=\Sigma_o$

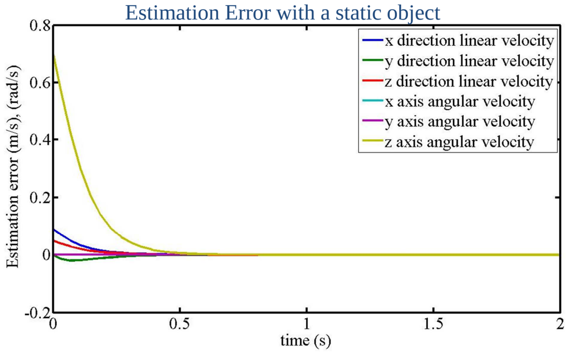
Camera settings

- Focal length $\lambda=0.0064$
- Hypcrbolic paramcters
  $a=0.0283$
  $b=0.0474$



Simulation Results for Pinhole Camera

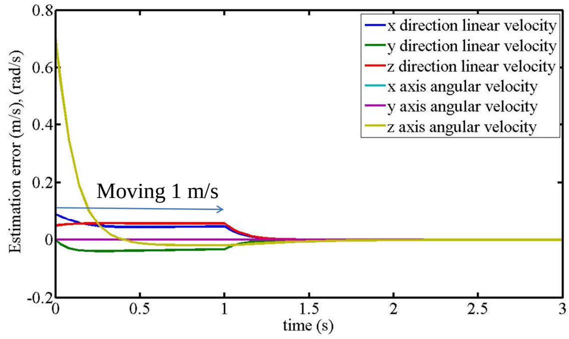
Estimation Error with a static object



Convergence

Simulation Results for Pinhole Camera

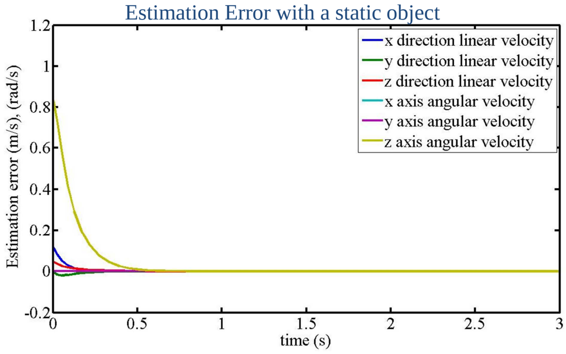
Estimation Error with object moving along a line



Convergence

Simulation Results for Panoramic Camera

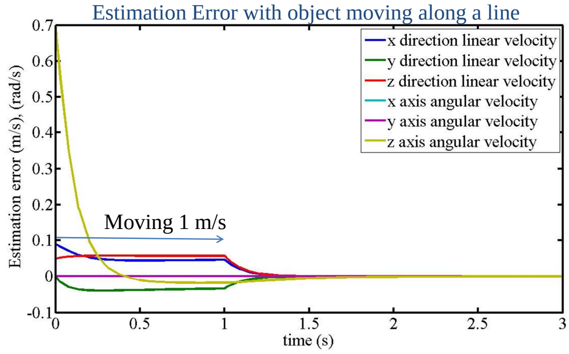
Estimation Error with a static object



Convergence

Simulation Results for Panoramic Camera

Estimation Error with object moving along a line



Convergence

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Conclusions and Future Work

Conclusions

- Study of the theory of a Visual Motion Observer
- Modeling of two different cameras
- Simulations of the Visual Observer with both cameras

Future Work

- Conduct experiments to verify simulation results
- Estimation using multiple cameras

References

[1] R. M. Murray, Z. Li, S. S. Sastry. *"A Mathematical Introduction to Robotic Manipulation"*, CRC Press, 1994

[2] M. Fujita, H. Kawai, M. W. Spong, "Passivity-based Dynamic Visual Feedback Control for Three Dimensional Target Tracking: Stability and L_2-gain Performance Analysis", *IEEE Transactions on Control Systems Technology*, Vol.1, No. 11, November 2002

[3] H. Kawai, T. Murao, M. Fujita, "Passivity-based Visual Motion Observer with Panoramic Camera for Pose Control"