Moving object detection, tracking and following using an omnidirectional camera on a mobile robot

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INVENTEURS DU MONDE NUMÉRIQUE

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ACROSS Centre of Research Excellence for Advanced Cooperative Systems

Outline

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Introduction

- working with a 360° field-of-view

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- widely utilized sensor in navigation, SLAM, visual odometry

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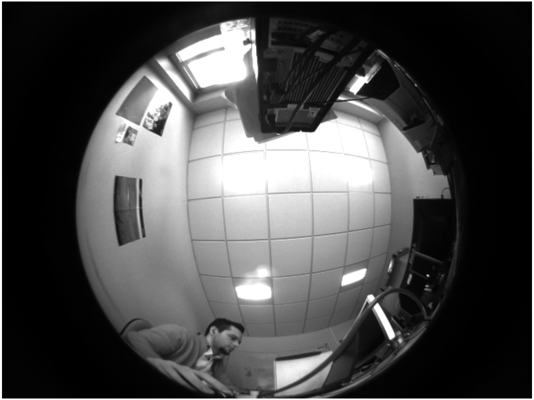
- widely utilized sensor in navigation, SLAM, visual odometry
- additional cue in sensor fusion
- robust moving object detection and tracking

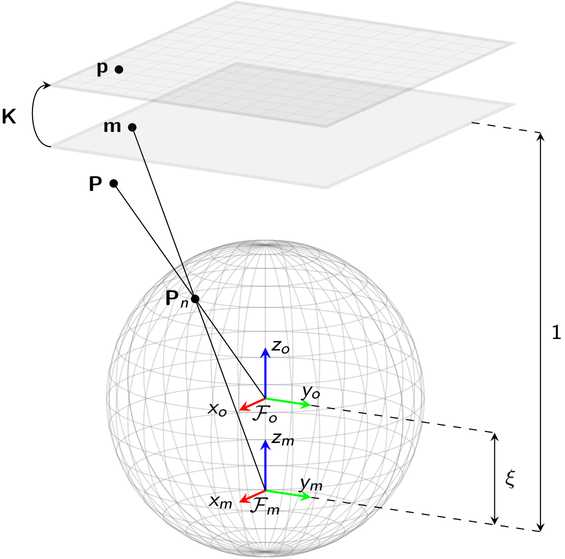
Outline

Omnidirectional image

- spherical projection model
  [Geyer and Daniilidis, 2000, Barreto and Araújo, 2001]
- unifies image formation in central catadioptric systems and (in practice) fish-eye lenses [Ying and Hu, 2004]



Spherical projection model



Calibration

- method proposed in [Mei and Rives, 2007]
- from pixel to a point on the sphere

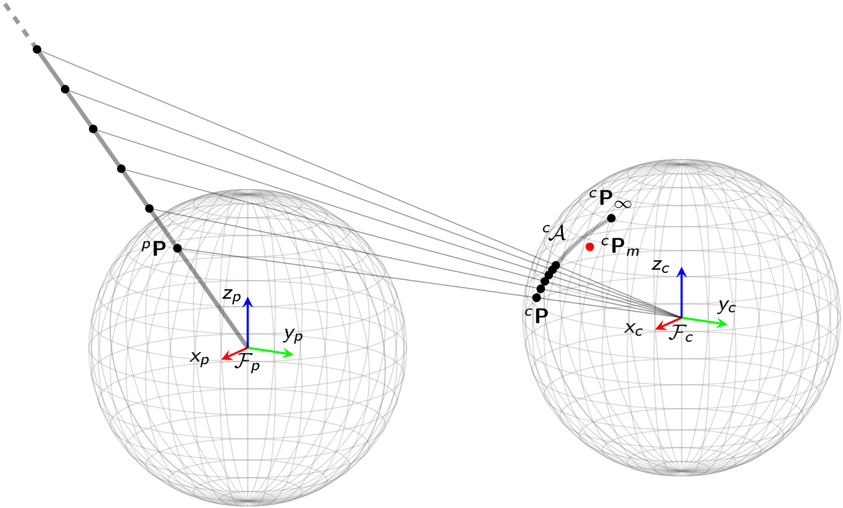
$$\boldsymbol{m} = \mathbf{K}^{-1}\boldsymbol{p}$$

$$\boldsymbol{P}_n = \begin{bmatrix} \frac{\xi+\sqrt{1+(1-\xi^2)(x^2+y^2)}}{x^2+y^2+1}x \\ \frac{\xi+\sqrt{1+(1-\xi^2)(x^2+y^2)}}{x^2+y^2+1}y \\ \frac{\xi+\sqrt{1+(1-\xi^2)(x^2+y^2)}}{x^2+y^2+1} - \xi \end{bmatrix}$$

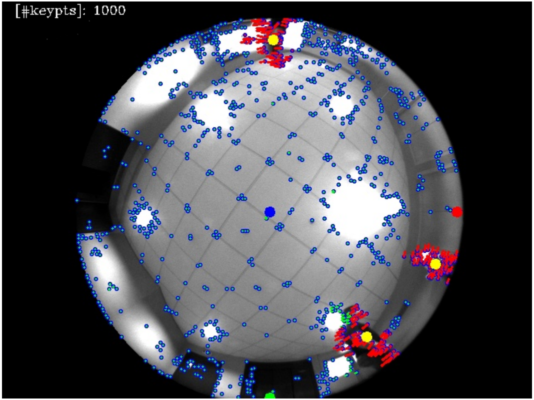
Moving object detection

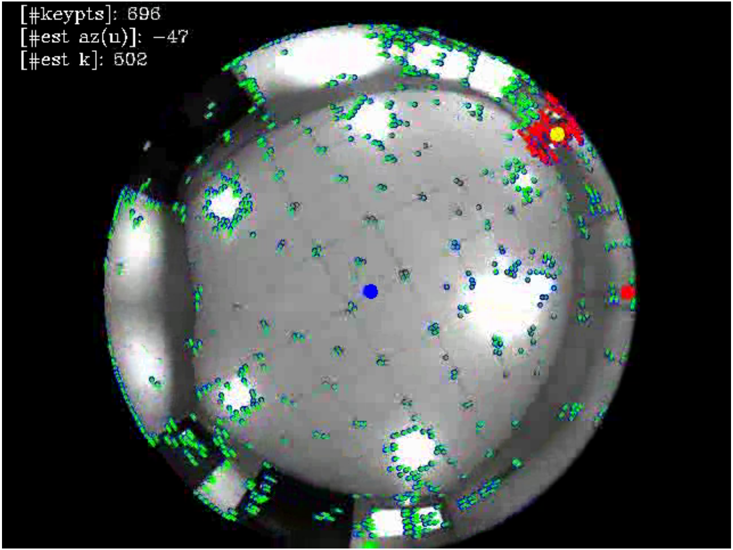
- optical flow is a confluence of camera motion, independent object motion, and the 3D structure of the scene [Palmer, 1999]
- corner detection and pyramidal Lucas-Kanade algorithm (sparse optical flow) [Bouguet, 2000]
- discrimination based on odometry (no depth information)

Camera displacement



- disjoint-set union find algorithm
- each cluster yields a point on the sphere




[#keypts]: 696
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Outline

Recursive Bayesian tracking

- estimate $p(\boldsymbol{x}_k|\boldsymbol{z}_{1:k})$—sequence of prediction-correction steps

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- prediction via

$$p(\boldsymbol{x}_k|\boldsymbol{z}_{1:k-1}) = \int p(\boldsymbol{x}_k|\boldsymbol{x}_{k-1})p(\boldsymbol{x}_{k-1}|\boldsymbol{z}_{1:k-1})\,\mathrm{d}\boldsymbol{x}_{k-1}$$

Recursive Bayesian tracking

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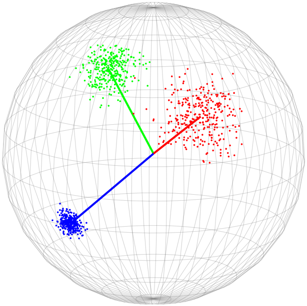
- correction via Bayes rule

$$p(\boldsymbol{x}_k|\boldsymbol{z}_{1:k}) = \frac{p(\boldsymbol{z}_k|\boldsymbol{x}_k)p(\boldsymbol{x}_k|\boldsymbol{z}_{1:k-1})}{p(\boldsymbol{z}_k|\boldsymbol{z}_{1:k-1})}$$

- a distribution on the unit sphere

$$p(\boldsymbol{x}; \kappa, \boldsymbol{\mu}) = \frac{\kappa}{4\pi \sinh \kappa} \exp\left(\kappa \boldsymbol{\mu}^{\mathrm{T}} \boldsymbol{x}\right),$$

where $\boldsymbol{\mu}$ is the mean direction vector and κ is the concentration parameter



Tracking with the vMF [Chiuso and Picci, 1998]

- prediction—solve the integral

$$\boldsymbol{\mu}_{k|k-1} = \boldsymbol{\mu}_{k-1},$$
$$\kappa_{k|k-1} = A^{-1}(A(\kappa_{k-1})A(\kappa_Q)), \quad A(\kappa) = \frac{1}{\tanh\kappa} - \frac{1}{\kappa}$$

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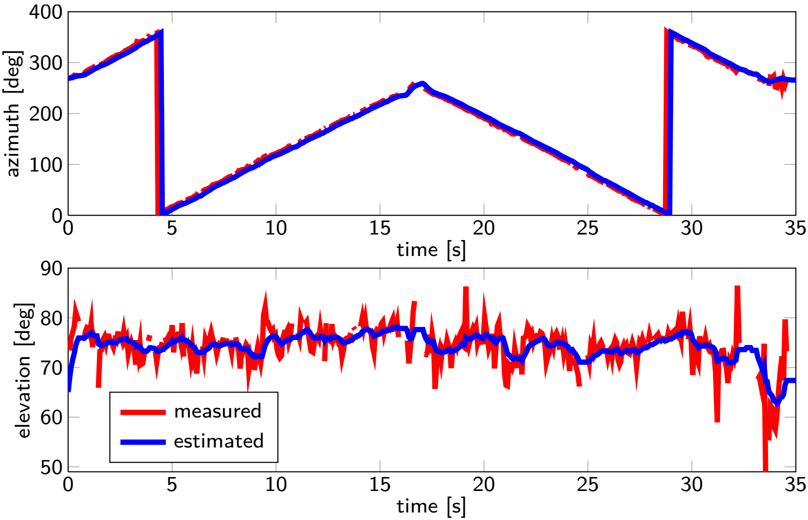
- correction—calculate the Bayes rule

$$\boldsymbol{\mu}_{k|k} = \frac{\kappa_{k|k-1}\boldsymbol{\mu}_{k|k-1} + \kappa_R \mathbf{z}_k}{\kappa_{k|k}}$$
$$\kappa_{k|k} = \sqrt{\kappa_{k|k-1}^2 + \kappa_R^2 + 2\kappa_{k|k-1}\kappa_R(\boldsymbol{\mu}_{k|k-1} \cdot \mathbf{z}_k)}$$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time [s]

Outline

Visual servoing [Chaumette and Hutchinson, 2008]

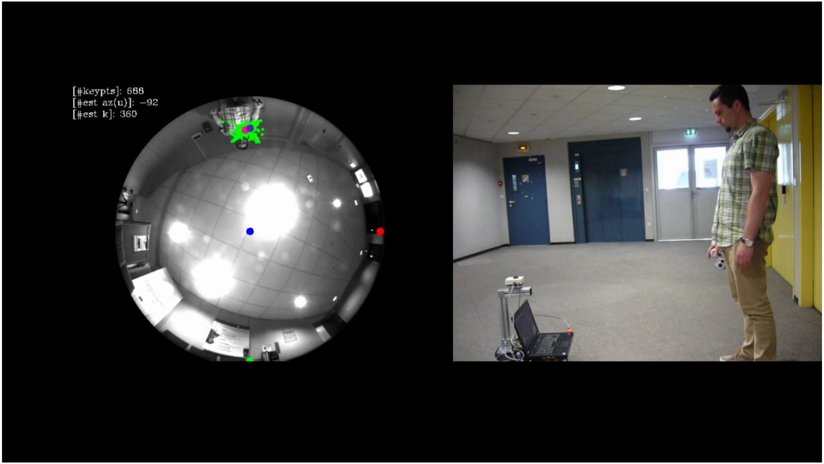
- cylindrical coordinates in the image [Iwatsuki and Okiyama, 2005, Fomena, 2008]

$$\begin{bmatrix} \dot{\rho} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \frac{-\cos\theta}{P_z} & 0 \\ \frac{-\sin\theta}{\rho P_z} & -1 \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix} = \mathbf{L}_s \begin{bmatrix} v \\ \omega \end{bmatrix}$$

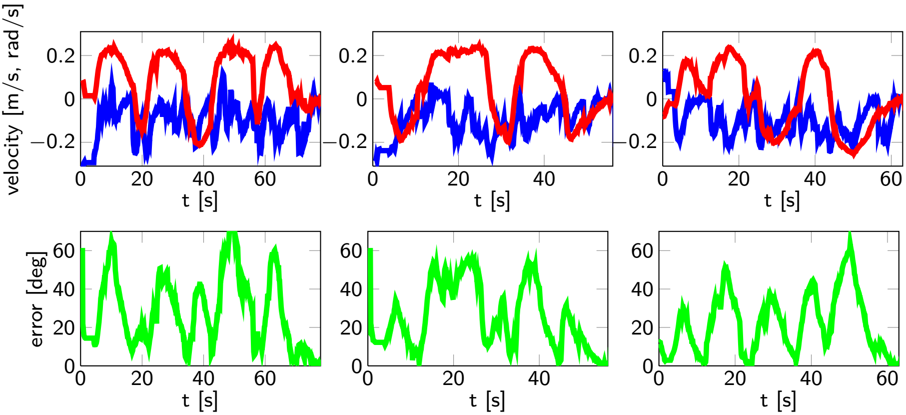
- control law

$$\begin{bmatrix} v \\ \omega \end{bmatrix} = -\lambda \hat{\mathbf{L}}_s^{-1} \begin{bmatrix} \rho - \rho^* \\ \theta - \theta^* \end{bmatrix}$$

Following via visual servoing



Experiments



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Conclusion

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- spherical representation — von Mises-Fisher tracker
- following via visual servoing

Conclusion

- detection and tracking of moving objects in omnidirectional images
- spherical representation — von Mises-Fisher tracker
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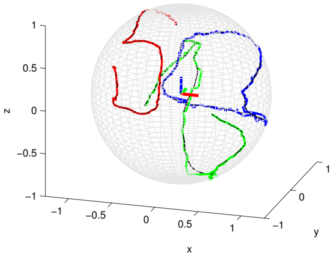

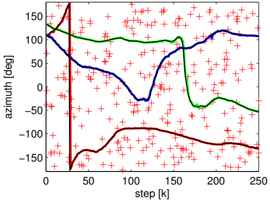

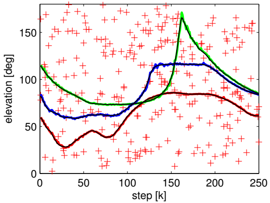

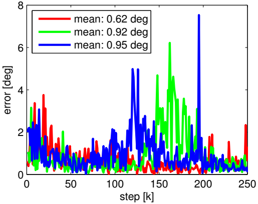

Thank you for your attention!

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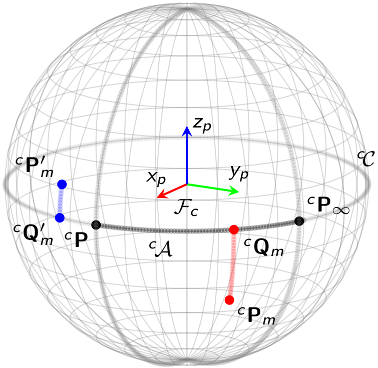
Distance to great circle arc



Distance to great circle arc

- great circle arc defined by ${}^c\boldsymbol{P}$, ${}^c\boldsymbol{P}_\infty$
- find closest point to matched ${}^c\boldsymbol{P}_m$ on the great circle

$$\boldsymbol{P}' = {}^c\boldsymbol{P}_m - ({}^c\boldsymbol{P}_m \cdot n)n, \quad n = {}^c\boldsymbol{P}_m \times {}^c\boldsymbol{P}_\infty$$

$${}^c\boldsymbol{Q}_m = \frac{\boldsymbol{P}'}{|\boldsymbol{P}'|}$$

- check if in the lune $({}^c\boldsymbol{P}, {}^c\boldsymbol{P}_\infty)$

$$({}^c\boldsymbol{P} \times {}^c\boldsymbol{Q}_m) \cdot ({}^c\boldsymbol{Q}_m \times {}^c\boldsymbol{P}_\infty) > 0 \,\&\&$$
$$({}^c\boldsymbol{P} \times {}^c\boldsymbol{Q}_m) \cdot ({}^c\boldsymbol{P} \times {}^c\boldsymbol{P}_\infty) > 0$$

- great circle distance

$$d(\boldsymbol{P}, \boldsymbol{Q}) = \arccos(\boldsymbol{P} \cdot \boldsymbol{Q})$$