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Application of Image Moment Flow of a RPP to 6 DOF Visual Tracking

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Abstract

The image moment flow of a rigid planar patch (RPP) is derived explicitly in this paper. From that derived relation, one can estimate the pose information of the RPP and, further, track a 6 DOF RPP using a properly designed visual feedback control.

1 Introduction

As the robot is required to perform more and more complex tasks for practical use, the requirement of visual application has gradually changed from the analysis of static visual information to the dynamical visual tracking [1]-[4]. In order to let the visual tracking algorithms easily satisfy the real-time requirement, we have concentrated on finding the characteristics of the *image moment* of a RPP.

2 Preliminaries

In the following description, the frame information will be revealed by the left superscript and the left subscript, and $\{w\}$, $\{c\}$, $\{o\}$ denote the world frame, the camera frame, and the object frame, respectively. The left subsctipt denotes the destination frame, or just the adopted frame, and the left superscript denotes the original frame, or the active frame.

2.1 Frame Operation

Under the condition ${}_2P$ is fixed, the following equations are assumed to be well-known:

$$ {}_1P = {}^2_1R\, {}_2P + {}^2_1T, \tag{1}$$

$$\begin{aligned} {}_1\dot{P} &= {}^2_1\omega \times {}_1P + {}^2_1k \\ &= {}^2_1\dot{R}\, {}_2P + {}^2_1\dot{T}, \end{aligned} \tag{2}$$

2.2 Rigid Planar Patch

The RPP, *rpp*, is a rigid object which can be entirely contained in a plane. Therefore, we can attach an object frame $\{o\}$ to this object such that

$$P \in rpp \implies {}_oP_z = 0.$$

And, we will let $\begin{bmatrix} s \\ t \end{bmatrix} = \begin{bmatrix} {}_oP_x \\ {}_oP_y \end{bmatrix}$ be the coordinate in the RPP plane. According to above consideration,

$$ {}_c\dot{P} = \begin{bmatrix} {}^o_c\omega_y z - {}^o_c\omega_z y + q_1\, {}^o_ck_x x + q_2\, {}^o_ck_x y + q_3\, {}^o_ck_x z \\ {}^o_c\omega_z x - {}^o_c\omega_x z + q_1\, {}^o_ck_y x + q_2\, {}^o_ck_y y + q_3\, {}^o_ck_y z \\ {}^o_c\omega_x y - {}^o_c\omega_y x + q_1\, {}^o_ck_z x + q_2\, {}^o_ck_z y + q_3\, {}^o_ck_z z \end{bmatrix}, \tag{3}$$

where $q = \frac{1}{{}^o_cR_3 \cdot {}^o_cT}\, {}^o_cR_3$.

2.3 Camera Model

In this paper, the camera model is assumed to be perspective projection. Then, the transformation from the RPP plane to the camera plane will be

$$\begin{bmatrix} u \\ v \end{bmatrix} = f \begin{bmatrix} \frac{{}^o_cR_{11}s + {}^o_cR_{12}t + {}^o_cT_1}{{}^o_cR_{31}s + {}^o_cR_{32}t + {}^o_cT_3} \\ \frac{{}^o_cR_{21}s + {}^o_cR_{22}t + {}^o_cT_2}{{}^o_cR_{31}s + {}^o_cR_{32}t + {}^o_cT_3} \end{bmatrix}. \tag{4}$$

3 Image Moments of the RPP and Their Flows

Here, we only discuss the image moments of binary images.

3.1 Original Image Moment

The image moment with (i, j)-th order is defined by

$$\begin{aligned} m_{ij} &= \iint_{(s,t)\in rpp} u(s,t)^i v(s,t)^j \,du dv \\ &= {}^o_cR_3 \cdot {}^o_cT \iint \frac{f^{i+j+2}\, {}_cx^i(s,t)\, {}_cy^j(s,t)}{{}_cz^{i+j+3}(s,t)} ds dt. \end{aligned} \tag{5}$$

From (5), and applying (3) and the definition of q, the derivative of the (i,j)-th moment is

$$
\begin{aligned}
\dot{m}_{ij} &= \left(-\frac{i+j+3}{f} m_{i(j+1)} - jf m_{i(j-1)}\right) {}^{o}_{c}\omega_x \\
&\quad \left(\frac{i+j+3}{f} m_{(i+1)j} + if m_{(i-1)j}\right) {}^{o}_{c}\omega_y \\
&\quad \left(-im_{(i-1)(j+1)} + jm_{(i+1)(j-1)}\right) {}^{o}_{c}\omega_z \\
&\quad \big((i+1)q_1 m_{ij} + iq_2 m_{(i-1)(j+1)} \\
&\qquad + ifq_3 m_{(i-1)j}\big) {}^{o}_{c}k_x \\
&\quad \big(jq_1 m_{(i+1)(j-1)} + (j+1)q_2 m_{ij} \\
&\qquad + jfq_3 m_{i(j-1)}\big) {}^{o}_{c}k_y \\
&\quad \left(-\frac{i+j+3}{f} q_1 m_{(i+1)j} - \frac{i+j+3}{f} q_2 m_{i(j+1)}\right. \\
&\qquad \left. -(i+j+2)q_3 m_{ij}\right) {}^{o}_{c}k_z \\
&= A_{ij}(m_{ext}, q) \begin{bmatrix} {}^{o}_{c}\omega \\ {}^{o}_{c}k \end{bmatrix}. \qquad (6)
\end{aligned}
$$

Combining different moment flow equations, we can thus obtain a suitable *image moment flow system*

$$\dot{m} = A(m_{ext}, q) \begin{bmatrix} {}^{o}_{c}\omega \\ {}^{o}_{c}k \end{bmatrix}, \qquad (7)$$

where the symbol m_{ext} means that the matrix A should reference to the moments which do not belong to m.

3.2 Normalized Image Moment

Sometimes, normalized image moment can lead to better performance, which is defined to be

$$\overline{m}_{ij} = \frac{m_{ij}}{m_{00}}, \qquad (8)$$

then,

$$\dot{\overline{m}}_{ij} = \overline{A}_{ij}(\overline{m}_{ext}, q) \begin{bmatrix} {}^{o}_{c}\omega \\ {}^{o}_{c}k \end{bmatrix}. \qquad (9)$$

3.3 Point Feature

Point feature can been seen as an RPP with very small area. By simple approximation and reduction, the optical flow equation can be derived.

4 Moment-Based Visual Tracking

Under the dynamical equation (7), the proposed Lyapunov-based control is

$$
\begin{aligned}
&\begin{bmatrix} {}^{o}_{c}\omega \\ {}^{o}_{c}k \end{bmatrix} \\
&= -\pi(|e^T \dot{m}_d| + \sigma) \frac{PA^t(m_{ext}, q)e}{|e^t A(m_{ext}, q) P A^t(m_{ext}, q) e| + \epsilon},
\end{aligned}
$$

where $e = m - m_d$, σ and ϵ are positive numbers, and P is a positive definite gain matrix.

5 Simulation Results

In this simulatin, one of the object's face contains three RPPs. Our objective is to visually track this moving object by moment measurement. From Fig.1, we can see that the moments converge to the desired moments asymptotically.

6 Conclusion

In this paper, we developed a new technique to treat with the image moments of RPPs. Through the moment flow equations and properly designed control law, visual tracking can be achieved and the effectiveness was demostrated by the simulation result.

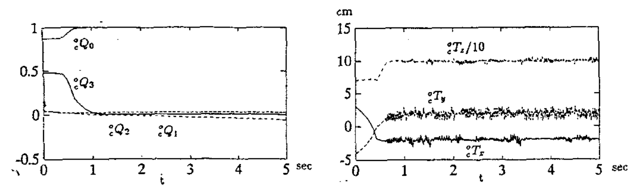

Fig. 1 practical pose trajectory in Example 1

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