Visual Servoing Using Trifocal Tensor

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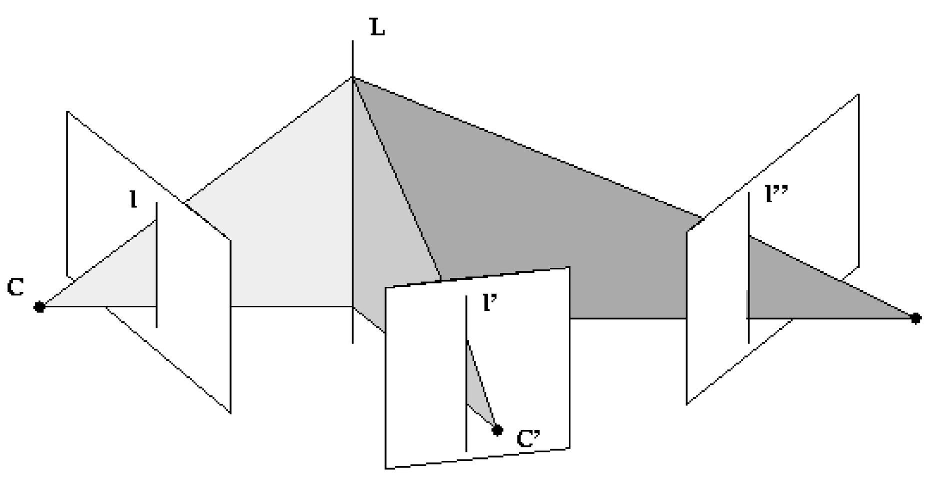
1. Introduction

Visual servoing is an approach for controlling the motion of a robotic system from visual measurements [1]. The trifocal tensor is well known in computer vision for tracing geometric information from three images of the same scene [2]. The trifocal tensor geometric model is more robust than the two view geometry models as it involves the information given by a third view, and the set of correspondences obtained is more robust to outliers.



Let the Camera positions be C_{c^*}, C_c, C_i for the desired, current, and initial camera positions respectively. And their projection matrices are $[I|0]$, $[{}^c\mathbf{R}_{c^*}|{}^c\mathbf{t}_{c^*}]$, $[{}^i\mathbf{R}_{c^*}|{}^i\mathbf{t}_{c^*}]$. The Tensor relationfor calibrated cameras can then be expressed as follows:

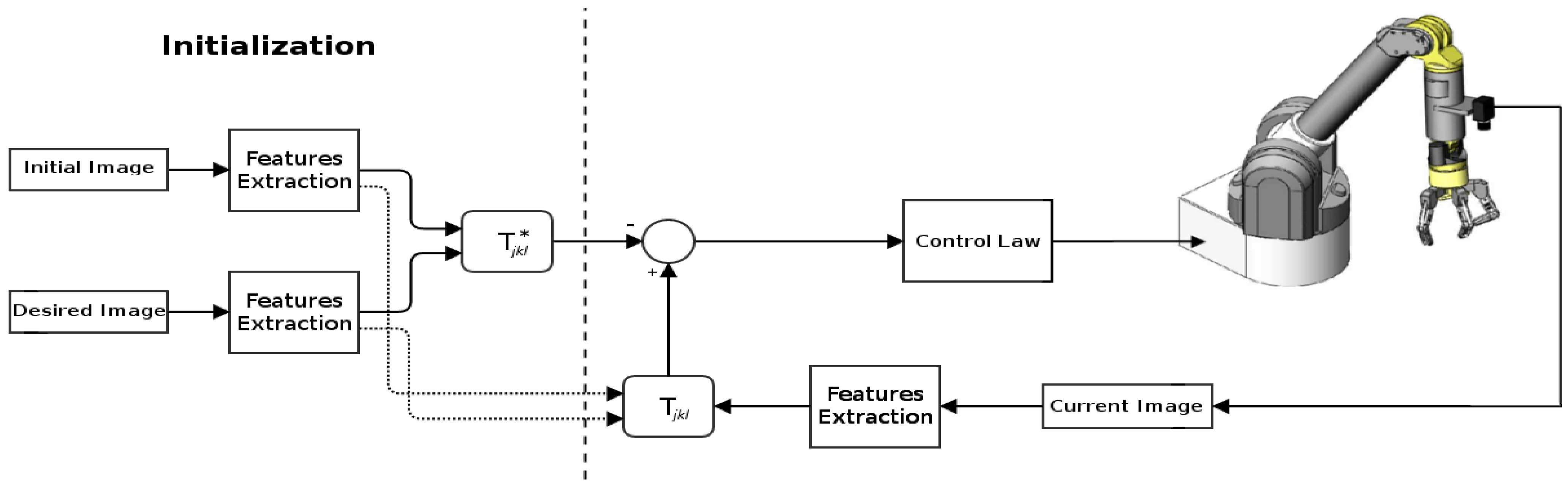
$$\mathcal{T}_{(jkl)} = {}^cR_{c^*(kj)}\ {}^it_{c^*(l)} - {}^ct_{c^*(k)}\ {}^iR_{c^*(lj)}$$

The trifocal tensor can be computed from feature correspondences across the three views [2]. Each triplet of corresponding image points gives 4 equations linearly independent. Therefore, a minimum set of 7 correspondences of points are needed for the trifocal tensor computation to uniquely determine the 27 entries of the tensor matrix.

2. Contributions

An approach to incorporate the trifocal tensor estimated from the calibrated three-view geometry into the visual servoing control loop task is proposed. This approach presents a generalized 6-DOF visual servoing task, with the control loop being closed over projective measures, namely the trifocal tensor coefficients. To the best of our knowledge, this approach is the first to propose a fully analytical design for a 6-DOF visual servoing task based on the trifocal tensor [3][4].

3. Methodology



Since the trifocal tensor is computed up to a scale factor, we propose a normalization step to get a fixed scale. The normaliztion factors $\mathcal{T}_{kN}$ are used to obtain the normalized tensor T_{jkl}.

$$T_{jkl} = \frac{\mathcal{T}_{jkl}}{\mathcal{T}_{kN}}, \mathcal{T}_{kN} = \Big(\sum_n \sum_m \mathcal{T}_{nkm}{}^2\Big)^{\frac{1}{2}}$$

The derivation of the normalized trifocal tensor corresponding interaction matrix $L_{T_{(jkl)}}$ is then:

$$\begin{aligned}
\dot{T}_{(jkl)} &= L_{T_{(jkl)}} u_c \\
&= \frac{{}^iR_{c^*(lj)}}{\mathcal{T}_{kN}} v_{c(k)} + \sum_m [\omega_c]_{\times(km)} T_{(jml)} \\
&\quad - T_{(jkl)}\Big(\sum_n \sum_m T_{nkm} \frac{{}^iR_{c^*(mn)}}{\mathcal{T}_{kN}}\Big) v_{c(k)} \\
&\quad + T_{(jkl)}\Big(\sum_n \sum_m T_{nkm} T_{nhm}\Big) \omega_{(g)} \\
&\quad - T_{(jkl)}\Big(\sum_n \sum_m T_{nkm} T_{ngm}\Big) \omega_{(h)}
\end{aligned}$$

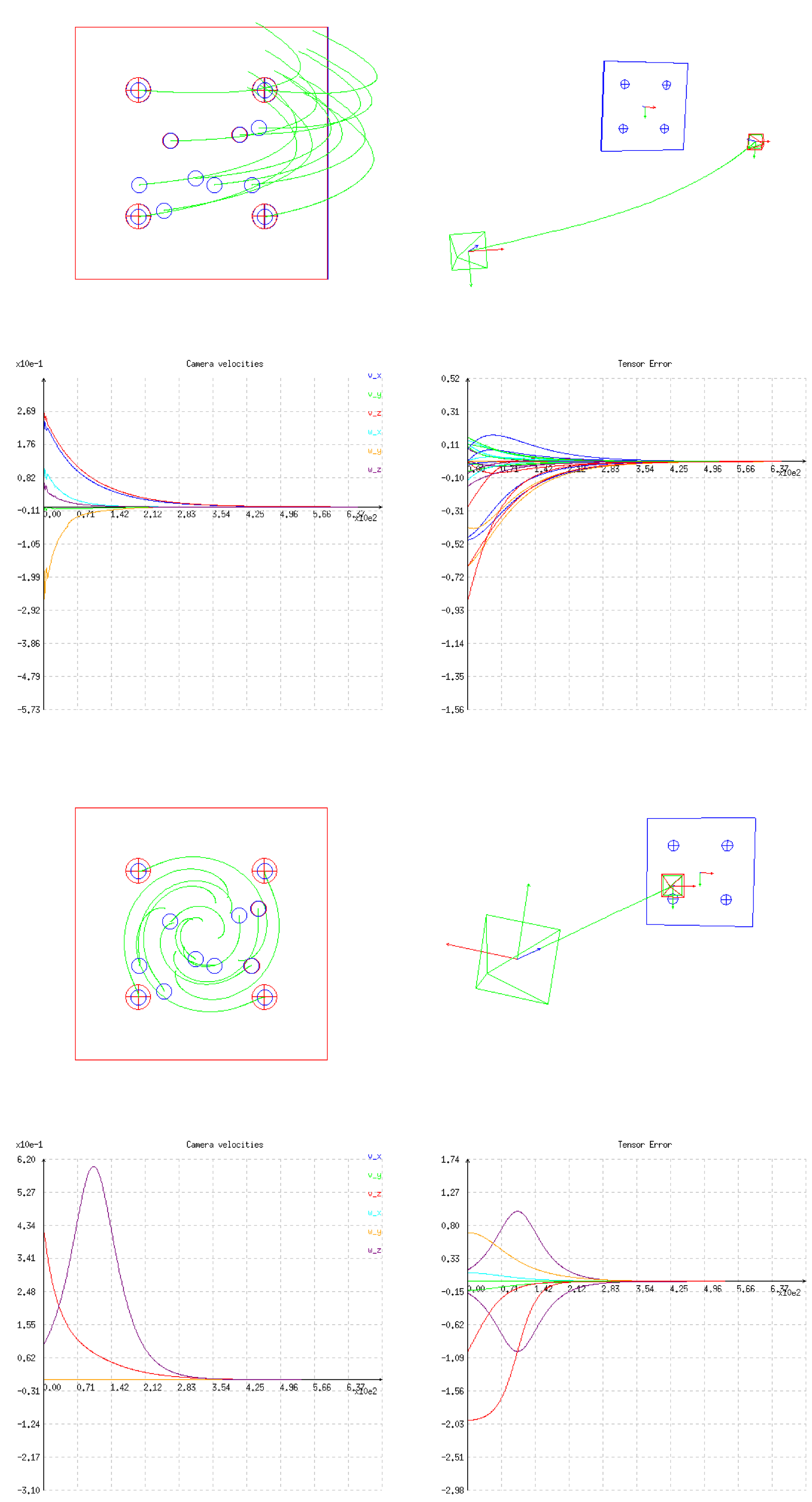
where $g = k\%3 + 1, h = (k+1)\%3 + 1$

With all elements defined, the control law is computed, and the visual servoing task is as follows:

$$e = T_{(jkl)} - T^*_{(jkl)}$$
$$u_c = -\lambda L^+_{T_{(jkl)}} e$$

1. At initialization, the desired tensor $T^*_{(jkl)}$ is computed from feature correspondences across the three images.
2. The current tensor $T_{(jkl)}$ is computed inside the visual servoing loop at each iteration.
3. The interaction matrix $L_{T_{(jkl)}}$ is computed using the current tensor.
4. The required velocities to drive the camera to the desired pose are computed with the new error value and the pseudo-inverse of the interaction matrix.
5. The system converges and the loop is terminated when the camera reaches the desired pose, means the error value is less than a defined threshold.

4. Results



1. The approach is working practically with very satisfactory results.
2. Does not suffer from some of the problems existing in IBVS methods namely the retreat problem.
3. In the interaction matrix, we have a decoupling between the translational velocities, means smooth camera trajectories for the motion in the 3D space.

However, the initial rotation matrix is a parameter that needs to be estimated.

5. Bibliography

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[4] A. Shademan and M. Jagersand, "Three-view uncalibrated visual servoing," in *Intelligent Robots and Systems (IROS), 2010 IEEE/RSJ International Conference on*. IEEE, 2010, pp. 6234–