On the normality of the projection parameters

Axel Fùrlan [*] **Daniele Marzorati** [**] **Domenico G. Sorrenti** [*]

[*] *Univ. di Milano - Bicocca, Italy (furlan@disco.unimib.hit)*
[**] *Info Solution S.p.A., Italy (d.marzorati@infosolution.it)*
[***] *Univ. di Milano - Bicocca, Italy (domenico.sorrenti@unimib.hit)*

Abstract: In autonomous navigation vision-based approaches are increasingly widespread; autonomous navigation techniques can be useful in indoor, both for robots and for human assistance, and in outdoor, for the navigation of artificial agents like rovers, cars, etc. A common assumption for such techniques is the normality of the measures on the image plane as well as the normality of the projection parameters. On one hand, the Gaussian assumption about the measures on the image plane is quite a reasonable assumption. On the other, we are interested in evaluating whether the estimate of the projection parameters is normally distributed. The projection parameters are today usually estimated during a calibration procedure, i.e., no datasheets for such parameters. The calibration procedure is implemented in various ways, though a very few calibration systems are in widespread usage in these days, see e.g., Bradski (2000), Bouguet (2010), which are largely based on the research presented in Zhang (2000).
In the systems above a non linear approach is used to estimate the projection parameters, starting from the image (2D) and scene (3D) coordinates of a set of calibration points. We are also interested in the quantitative estimation of the intensity of the uncertainty on the projection parameters, basing on the a priori uncertainty on image measurements. Indeed, the two most used systems mentioned above completely ignore the a priori information about the accuracy we can get while measuring in the image plane. The system in Bouguet (2010) does provide the standard deviation of the parameters it estimates, but this uncertainty is computed as a statistic of the errors, i.e., the part of the data that is un-explained by the estimated model. We may name this as the statistic of the residuals. We, instead, believe that the information we have, about the image measurement process, can avoid the large underestimation of the uncertainty of the estimated parameters that is implicit in the residual statistic.
It is worth noting that underestimation of the uncertainty on the projection may lead to fatal mistakes in the subsequent filtering steps, which make use of the projection. This is typically due to misses in data-association, e.g., between the current estimate of a point of the scene and the subsequent measures of the same scene point. From this point of view, we believe every uncertainty source should be taken into account and used for more accurate estimates, and this applies to projection parameters as well.
The issue considered in this paper is: is it true that the projection parameters, as produced by common calibration systems, are normally distributed? In order to verify this (commonly accepted) thesis, we implemented a Particle Transform and, assuming (as stated before) that the measures on the image plane and in the scene are normally distributed, we transformed the a priori uncertainty of each calibration point through the calibration procedure. It turns out that the resulting distribution is still normal. Moreover, in this paper we do also determine the intensity, i.e., the standard deviation, of the normal uncertainty. Although computing the uncertainty intensity is intrinsic to the Particle Transform, it is actually computationally expensive. Since we proved that the posterior distribution is Gaussian, we no longer need a particle set, to represent an arbitrary distribution. We implemented an Unscented Transform, which is known to perfectly suited to deal with normal distributions and is, at the same time, computationally much lighter than sampled transforms. A quite interesting aspect of the Unscented Transform does not require the explicit computation of the Jacobian of the transformation (i.e., the whole projection calibration procedure), which is not easily computable.
In conclusion, in this work we prove the commonly accepted thesis that the uncertainty on the projection parameters is Gaussian and provide a lightweight approach to estimate the intensity of such uncertainty.

Keywords: Projection model, Computer vision, Robot vision, Robot navigation, Particle Transform, Unscented Transform

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