Computer Vision Research at the University of Washington

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1 Ground-truthing RADIUS Images

Our work in the past year has emphasized the creation of an accurate ground truth data set for the RADIUS model board imagery[3]. The ground truthed data set provides labeled corresponding point positions on all images that the points occur as well as the 3D positions for 876 points on RADIUS model board 1 imagery and 532 points on RADIUS model board 2 imagery. For a nominal charge, this is now available from the University of Washington as a set of CDROMS.

To accomplish this required work in annotation, photogrammetry, and constrained optimization. Our work in annotation was described in [4]. After the labor intensive annotation was complete, we developed software for performing a multi-image spatial resection so that a simultaneous estimate for the interior parameter and exterior parameters using up to 1000 points per image and up to 50 images could be computed. A brief discussion of this can be found in Hudson et. al. (1996)[3]. Using this software, interior and exterior parameter estimates and their covariance matrices for each of the 78 RADIUS model board imagery is provided on the CDROMs. The CDROM also contain the source code for this software.

In addition, the edge boundaries for all buildings, building shadows, and clutter was traced by hand and labeled. This can be used to calculate statistics for these different kinds of boundaries. Such statistics are useful in vision algorithms that may classify edge boundaries in making 3D inferences. The reconstructed building models are also projected back onto all the images, with hidden line removal, providing on the CDROMs a geometrically consistent data set of building edge boundaries.

2 Bayesian Triangulation

Once interior and exterior orientation parameters are estimated for all cameras, the annotated corresponding points can then be used in a multi-image triangulation to estimate the positions for the 3D points. If there are errors in the labeling of the corresponding points, the estimated positions of the 3D points will be off. Such points can be discovered by projecting them onto the images and comparing their projected positions with the positions of the annotated points. A Bayesian analysis of the expected error compared with the observed error can be the basis of determining which corresponding points are incorrectly labeled. Details of this method can be found in Bedekar (1995)[1]. An interesting aspect of the Bayesian analysis is that the covariance matrix of the camera parameters is explicitly taken into account. As a result, the criterion function to be minimized in the triangulation problem becomes more complex than the usual least squares problem. But although the criterion function is more complex, the optimization actually can be computed in fewer iterations and is less sensitive to the starting values. Software for the Bayesian Triangulation is also provided on the CDROMs. In the next year we will be extending this method to automatically determine corresponding points on multi-image stereo imagery.

3 Constrained Optimization

In the case where corresponding points on mult-image stereo are the corner points of buildings, there are constraints. Buildings are polyhedra having various perpendicular and parallel angle relations among its lines and planes and having relations that certain points must lie on the same line or on the same plane. We call these relations partial models since they do not necessarily specify all the details of the 3D objects. Simple triangulation does not produce estimated 3D point positions that satisfy these kinds of relations. Given these partial models and the estimated positions of the 3D points, produced by a multi-image triangulation, we set up a constrained optimization problem to re-estimate 3D point positions that are guaranteed to satisfy the partial model. This produces estimates of building reconstructions that are not tilted or skewed. See Xufei (1996)[5] for details. The software for doing the constrained optimization is also provided on the CDROMs.

4 Statistical Validation of Software

During this past year we also looked at the problem of validating computer vision software. Vision software is often an implementation of an algorithm

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developed from a theoretical derivation. It is not unknown for derivations to have assumptions which are wrong, approximations which are not good enough, or simply involve an incorrect inference. It is not unknown for a vision algorithm to have an implementation bug. There is a way of validating which validates a software implementation and the theory on which it is based simultaneously. The methodology is called statistical validation.

In statistical validation, an ideal data set is created that satisfies all assumptions in the theory. Associated with this data set is the true value of the unknown parameters that the vision algorithm is to infer from the data set. Since the data set is ideal, the vision software will, of course, compute an inference which is equal to the true value of the unknown parameters.

Using error propagation techniques as discussed in [2] the covariance matrix of the inferred parameters can be analytically computed if the covariance matrix of the random perturbation affecting the ideal data is known. Using this fact, we can do the following. Each element in the data set can be repeatedly perturbed by a random perturbation coming from a known distribution. The values of the inferred parameters are then computed by the vision software. This produces a data set of inferred parameter values, each one of which comes from a population having the analytically determined covariance matrix. In statistical validation, the sample of inferred parameters is tested to see if we can reject the hypothesis that it has a mean value equal to the ideal value and a covariance matrix equal to the derived covariance matrix. If we cannot reject the hypothesis, then we can say that the software has been statistically validated. Details of this procedure are discussed in [6], where the procedure is applied to the constrained optimization software used in producing the final ground truth in the RADIUS model board imagery data set. Software for doing this kind of hypothesis testing is also provided on the CDROMs.

References

[1] A. Bedekar, "A Bayesian Method for Triangulation," (with A.S. Bedekar), *ICIP-95: Proceedings, International Conference on Image Processing*, Washington, DC, Vol. II, October 23–26, 1995, 362–365.

[2] R. Haralick, "Propagating Covariance in Computer Vision", *Proceedings of the 12th IAPR International Conference on Pattern Recognition: Conference A: Computer Vision and Image Processing*, Jerusalem, Israel, October 9–13, 1994, Vol. I, 493–498.

[3] W.H. Hudson, D.C. Nadadur, K. Thornton, X. Liu, and R. Haralick, "The RADIUS Imagery CDROM Ground Truthed Data Set," *Proceedings ARPA Image Understanding Workshop*, Palm Springs CA Feb, 1996.

[4] K. Thornton, D.C. Nadadur, V. Ramesh, X. Liu, X. Zhang, A. Bedekar, and R. Haralick, "Groundtruthing the RADIUS Model-Board Imagery," *Proceedings, ARPA Image Understanding Workshop*, Monterey, CA, November 13–16, 1994, Vol. I, 319–329.

[5] Xufie Liu, R. Haralick, and K. Thornton, "Site Model Construction Using Geometric Constrained Optimziation," *Proceedings ARPA Image Understanding Workshop*, Palm Springs CA Feb, 1996.

[6] Xufei Liu, T. Kanungo, R. Haralick, " Statistical Validation of Computer VIsion Software," *Proceedings ARPA Image Understanding Workshop*, Palm Springs CA Feb, 1996.