A COMPUTATIONAL FRAMEWORK
FOR
STEREO IMAGING

BY

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THESIS
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To my family
Abstract

Stereo vision recovers depth information from a 3-D scene by exploiting differences between two different 2-D projections. This involves two processes: analysis and reconstruction. The former estimates camera parameters – calibration – and obtains the relative position of the same 3-D point in the two different images – correspondence estimation. The latter deals with the extraction of the 3-D scene information. These two ill-posed problems are the focus of research in stereo imaging.

In this thesis a complete framework for stereo analysis is proposed. New strategies are devised to deal with the underlying problems. With respect to the calibration problem a Tukey’s outlier detection technique and a scaling based on the Karhunen-Loève transform are proposed. A robust estimation procedure based on clustering and the Least Median of Squares technique is introduced. Additionally, the clustering uses correlation and redundancies in the magnitude and position of the disparity vectors. This leads to an approach which combines semivariograms and k-means strategies.

For the correspondence problem two similarity measures for disparity estimation are proposed. The first measure is based on the Pearson’s correlation coefficient where: a) the median is used instead of the mean and b) the $L_1 - norm$ is used instead of the $L_2 - norm$. The second measure uses a weighted sum of absolute differences exploiting the spatial variability in the correlation window. It uses the ordinary Kriging equations for the calculation of the values of the weights.

Image synthesis is used in the evaluation of disparity inaccuracies. Sensitivity analysis is conducted to assess the effect of disparity inaccuracies in the virtual images.

Specific contributions of this work are: analysis and development of a robust estimation technique for camera calibration, study of similarity measures for correspondence estimation, and sensitivity analysis for the evaluation of disparity estimation using intermediate (synthetic) images.
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The Road Not Taken

Two roads diverged in a yellow wood,
And sorry I could not travel both
And be one traveler, long I stood
And looked down one as far as I could
To where it bent in the undergrowth;

Then took the other, as just as fair,
And having perhaps the better claim,
Because it was grassy and wanted wear;
Though as for that, the passing there
Had worn them really about the same,

And both that morning equally lay
In leaves no step had trodden black.
Oh, I kept the first for another day!
Yet knowing how way leads to way,
I doubted if I should ever come back.

I shall be telling this with a sigh
Somewhere ages and ages hence:
Two roads diverged in a wood, and I-
I took the one less traveled by,
And that has made all the difference.

Robert Frost (1874–1963)
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CHAPTER 1

INTRODUCTION

The vision system of biological creatures is based on the two eyes and the brain, where the eyes capture aspects of the 3-D physical information and the brain recovers the distance or third dimension. In an attempt to simulate this system, two cameras are used as the eyes for capturing 2-D projections – images – of the physical 3-D world-scene. A computer takes the place of the brain in the computational modelling, processing, and interpretation of the 2-D projections. This is the task of stereo vision: the recovery of the original physical 3-D information – depth – in a manner similar to the way biological creatures perceive depth.

Once the depth information is available, it is possible to represent – to render – it in a 3-D way. These representations become useful in different areas. For instance, in medicine it is useful for 3-D visualizations of internal organs for inspection and diagnosis. Three-dimentional teleconferencing is able to capture the attention of an audience for longer. A missile can locate the target with more accuracy by using the depth information. General applications areas are: Education [Chi1995, Bra2000,

1.1 The Stereo Vision Problem

The stereo vision problem can be defined as the recovery of the 3-D structure of a scene
from its 2-D image representations. This is an inverse problem. The forward problem
can be described using the structure of the problem in Figure 1.1 where the 3-D scene is
the input which is captured by a system – a camera – to produce 2-D images – the
output.

![Fig. 1.1.: The structure of a problem](image)

In general, an inverse problem consists of a model describing the relation between
an input – the 3-D scene – and an output – 2-D images – where the output is known and
the input have to be estimated. The solution of this problem is the estimated input that
satisfies the relation between the input and the output defined by the model.

Hadamard characterized a well-posed problem by the existence, uniqueness, and
stability of the solution [Had1923]. A problem which does not satisfy at least one of
these three conditions is called *ill-posed*. A consequence of the instability of an ill-posed
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problem is that small perturbations – measurement errors – in the data have large influence on the solution.

On the other hand, a linear classical problem is the solution of an integral equation. Using functional analysis [Ped1999], an inverse problem can be symbolized by means of the Fredholm integral equation:

\[ \int K(s,t) x(t) dt = y(s) \]  \hspace{1cm} (1.1)

where \( x(t) \) is the unknown functional, \( y(s) \) is a known right-hand-side and \( K(s,t) \) is called the kernel. The Fredholm integral equation is said to be the first-kind, if the unknown functional appears only inside the integral. When the first-kind Fredholm integral equation is made discrete – more details can be found in Hansen [Han1998] – it can be written as a system of linear equations. The system of linear equations can be expressed in matrix notation as:

\[ Kx = y. \]  \hspace{1cm} (1.2)

The inverse problem is to estimate \( x \) from \( K \) and \( y \). The problem is that the inverse \( K^{-1} \) is unbounded (if it exists). This is due to errors. Errors were added when the first-kind Fredholm integral equation was made discrete and more errors – rounding errors – are going to be added during the solution. The result is that the solution \( x \) might not be robust against perturbations. This fact is mirrored in a system of linear equations in the sense that the condition number of \( K \) is large.

An indicator of the instability of a system of linear equations is the condition number of the matrix \( K \) – in Equation (1.2). The condition number is a measure of the robustness of the solution to perturbation. A matrix with a large condition number is an ill-conditioned matrix [Gol1996].

The inverse problem – estimate \( x \) from \( K \) and \( y \) – is an ill-posed problem in the sense of Hadamard and neither a simple nor a complicated reformulation of the problem will improve the ill-posed problem. In a strict mathematical sense, we are not able to solve an ill-posed problem. However using \( a \ priori \) information we can obtain an answer close to the correct solution.
Regarding the stereo vision problem, in the forward problem a 3-D scene is captured by a camera to produce 2-D images. The inverse problem is to infer the 3-D information of the scene from a set of 2-D images. Moreover, there is the lack of information about depth that it makes the stereo vision problem an ill-posed problem in the original sense of Hadamard.

### 1.2 Stereo Vision Solution

The solution of the stereo vision problem is based on the recovery of 3-D information from a set of projection images. A stereo rig – two cameras looking at the same 3-D scene, in Figure 1.2 – is used in capturing the project images (output).

![Fig. 1.2.: Stereo rig](image)

Epipolar geometry is used for defining the relation between the 3-D scene (input) and the projection images (output):

\[
p_i^T F p_r = 0
\]  

(1.3)

The epipolar equation – in Equation (1.3) – is the model describing the geometry of the stereo system. It is a function of two corresponding points – \( p_i \) and \( p_r \) – in the left and right images, and a matrix \( F \) – the fundamental matrix.
The solution of stereo vision problem involves two processes: analysis and reconstruction. The former estimates camera parameters and obtains the relative position of the same 3-D point in the two different images. The latter deals with the extraction of the 3-D scene information.

In other words, the calibration problem is to obtain the geometry that describes the relation in the stereo system. The fundamental matrix, $F$ or $f$, encodes the geometry of the stereo system. Thus, the estimation of the fundamental matrix is known as the calibration problem. The estimation of corresponding points is known as the correspondence problem. Once the calibration and correspondence problems are addressed, the reconstruction of the 3-D scene is done by triangulation.

For the estimation of the fundamental matrix, we have to assume that a set of corresponding points is available. On the other hand, in order to reduce the search space and obtain a more reliable estimation of corresponding points, it is required that the images are calibrated. Hence the solution of the calibration problem is dependent on the solution of the correspondence problem and vice versa.

In the calibration problem, the epipolar equation can be written as a system of linear equations [Lon1981]. The linear equations can be expressed in matrix notation as:

$$U_n f = 0.$$

(1.4)

where the matrix $U_n$ contains the corresponding points information and the vector $f$ contains the elements of the fundamental matrix.

Linear methods for the estimation of the fundamental matrix are based on Equation (1.4). The matrix – in the system of linear equations – is ill-conditioned.

### 1.3 Thesis Statement and Contributions

The process of analyzing images of 3-D scenes taken from two different viewpoints in order to estimate depth is called stereo analysis. Stereo analysis plays an important role in a large number of applications such as robot navigation, augmented reality...
applications, and telecommunications. For instance, a crucial application of such technology is in videocommunication with telepresence. Usually this is implemented by means of autostereoscopic multiviewpoint technology that enables realistic 3-D impression. Such systems are underpinned at technical level by stereo analysis algorithms. The underlying models analyze the information supplied for a stereo camera in order to reconstruct 3-D scenes. In this thesis several aspects of stereo analysis are tackled. The main body of this work discusses and describes state-of-the-art stereo vision methods, examines the fundamentals of imaging geometry, and discusses the central problems in stereo analysis: the calibration and correspondence problems. Image synthesis is used for the evaluation of disparity estimations.

Calibration is focused on the estimation of the fundamental matrix using linear techniques. It is constrained by the instability of the solution – ill-posed problem – and the solution of a linear system of equations in which the matrix of the system is ill-conditioned. In order to obtain an estimation of the fundamental matrix, a set of corresponding points is used in the solution of the system of linear equation in (1.4). Since the corresponding points are estimations, they can contain outliers. The Tukey technique [Tuk1977] is used for identifying outliers in the input data. The solution of a linear system of equations – in which the matrix of the system is ill-conditioned – is tackled by using the Karhunen-Loève transform [Boz1995], while a detailed comparison to traditionally used methods is given. The instability of the solution provides the motivation for the use of robust statistics techniques: the Least Median of Squares technique is used in a Monte-Carlo scheme. In order to impose constraints on the distribution of the corresponding points used for the fundamental matrix estimation, a robust estimation procedure based on clustering and the Least Median of Squares technique is introduced. Additionally, the algorithm uses correlation and redundancies in the magnitude and the position of the disparity vectors. It utilises a model which combines a grid-semivariogram [Cre1993] and the k-means algorithm. A detailed comparison to Zhang [Zha1998] and Torr and Murray [Tor1993] approaches is presented.

The estimation of corresponding points depends on the similarity measure and the computational strategy. This work is centred in the similarity measures. In this respect, two novel measures of similarity are proposed. The first one, median correlation is based on Pearson’s coefficient of correlation, where the median is used instead of the
mean, and the $L_1$-norm is used instead of the $L_2$-norm. The second measure is a weighted sum of absolute differences. It exploits the spatial variability in the correlation window. The spatial correlation is measured using the semivariogram function to determine the range of influence. The values of the weights are determined using the ordinary Kriging technique [Cre1993]. In this way, points closer to the centre have larger weights than those distant from it. The performance of the proposed measures is compared to traditionally used measures.

Once the calibration and correspondence problem are addressed, a field containing the disparities between corresponding points is generated. This field is called a dense-disparity map. Image synthesis is used for the evaluation of disparity estimations. Sensitivity analysis is conducted to assess the quality of virtual images created using distorted disparity maps.

Specific contributions of this work are: analysis and development of a robust estimation technique for camera calibration, study of similarity measures for correspondence estimation, and sensitivity analysis for the evaluation of disparity estimation using intermediate (synthetic) images.

1.4 Structure of the thesis

This thesis is comprised of six main chapters, of which Chapter 2 presents a general overview of the stereo-vision problem and a review of the state-of-the-art. Chapter 3 presents the geometry for stereo images. Chapters 4 to 6 describe the three parts of the contributed elements of this work and Chapter 7 presents the experimental results.

Chapter 2 consists of three main parts. It presents concisely the stereo vision problem and contains a survey of the most representative contributions on calibration and correspondence problems, and image synthesis. Chapter 3 provides an explanation of the geometrical relation between a 3-D scene and its 2-D representations. Section 3.1 presents the pinhole camera model. Intrinsic and extrinsic parameters are introduced in Sections 3.2 and 3.3. The epipolar geometry is presented in Section 3.4. Sections 3.5 to
3.7 describe definitions of the essential matrix, the epipolar lines, and the fundamental matrix.

Chapter 4 contains a characterization of the geometric calibration problem. Section 4.1 presents techniques most commonly used in the estimation of the fundamental matrix. Techniques for normalization of the input data are presented in Section 4.2. We propose a scaling based on the Karhunen-Loève transform in Section 4.3. Sections 4.4 to 4.7 focus on the robust estimation of the fundamental matrix, which is justified by the characteristics of this problem. Section 4.7 proposes a robust estimation procedure based on clustering using spatial dependences among neighbouring disparity vectors and the Least Median of Squares technique.

Chapter 5 addresses the correspondence problem, which is studied from the measurements’ viewpoint. Section 5.1 presents the matching estimation problem, matching errors and constraints. The block-matching strategy is described in Section 5.2. Measures of correlation commonly used in the block-matching strategy, are presented in Section 5.3. We propose a robust correlation measure – the median correlation – based on Pearson’s coefficient of correlation, which uses the median and the $L_1$-norm in Section 5.4. In Section 5.5, we introduce the weighted sum of absolute differences, where the semivariogram function is used to determine the range of influence and the ordinary Kriging technique is used to determine the values of the weights.

Chapter 6 is concerned with the application of disparity estimations. Disparity estimation is in Section 6.1. Theoretical formulations for generating a virtual image using affine and Euclidean view synthesis are described in Sections 6.2 and 6.3. A technique based on interpolation is presented in Section 6.4. Using the hypothesis that ideal disparities cannot be estimated, we propose the use of sensitivity analysis for examining the effect of disparity inaccuracies in Section 6.5.

Chapter 7 presents experimental evaluations of techniques described in Chapters 4 to 6, and Chapter 8 contains the conclusions of this work and recommendations for further work.
In this thesis, a framework for stereo analysis was presented. New strategies were devised to deal with the underlying problems. With respect to the calibration problem the box-and-whisker plot was used in detecting outliers on disparity vectors. Outliers due to bad-location were identified by this technique. The results of the box-and-whisker analysis depend on the behaviour of the input data set. This technique cannot be used automatically; its results have to be validated before taking the decision to eliminate points. A scaling transformation based on the Karhunen-Loève transform (KLT) was proposed in order to deal with the ill-conditioned characteristic of the matrix of the system of linear equations. The KLT scaling produced slightly better results than the isotropic scaling. A circular, symmetric, and homogeneous selection of points was introduced. This led to a new scaling based on the centroids and the average radius. When the corresponding points are distributed homogeneously in the image, the estimation of the fundamental matrix is improved. However, it is possible to obtain sets of points belonging to the same object that make the estimation of the fundamental matrix unstable. Based on the fact that the estimation of the fundamental matrix is unstable when the points used for its computation lie on a small number of planes, a
clustering technique was introduced using disparity vectors. This technique forces the selection of at least one point from each plane. The k-means algorithm produced the best partition. In order to tackle the main drawback of the k-means algorithm – the dependence of the results on the initialization groups – a new strategy for establishing the initialization groups was proposed. This was based on grid clustering derived from the spatial dependence amongst disparity vectors, using the semivariogram parameter range to determine the grid size. The grid cluster information was used to determine the number of clusters and the initialization groups. The LMS was chosen as the robust statistics estimator because it has a high-breakdown point and is appropriate for this problem. The k-means and grid based on semivariogram clustering were introduced for selecting points in the LMS schema. An efficient least median of squares approach was derived by combining k-means and grid based on semivariogram clustering. This approach produces a better estimation of the scene geometry by including all disparities and spatial positions in the sample.

For the correspondence problem, we focused on similarity measures that are used in a block-matching scheme. The meaning of the word correlation was stated as: connection and concordance. The ground-truth correlation analysis shows that negative correlation scores are obtained in occlusion areas and areas of discontinuity. This result can be used for identification of those areas. The Median Correlation (MC) was proposed as a similarity measure for the estimation of corresponding points in stereo vision. Since, the MC can reach its maximum value more than once in the search window, a point in the left image may be paired to several points in the right image and vice versa. A relaxation technique is required in order to deal with these ambiguities. A weighted sum of absolute values (WSAD) was introduced considering the intensity differences as a spatial process. The spatial correlation was measured by using the semivariogram and the values of the weights were computed by solving the ordinary Kriging equations. Disparity maps obtained by using the WSAD show smooth disparities within the objects’ surfaces and the depth separations are preserved adequately. Objects in the foreground are easily identified; that makes WSAD suitable for depth segmentation. The correlation window size depends on the spatial variability. When there is large variability in the surrounding area a small correlation window size
is required. On the other hand, when there is small variability in the surrounding area a
large correlation window size has to be used.

Intermediate virtual images were used in the evaluation of disparity inaccuracies. Sensitivity analysis was conducted to assess the effect of disparity inaccuracies in the virtual images. A visual error measure was proposed in order to approximate the subjective error perception of the human eye. Regarding the magnitude of the perturbations, PSNR values decreased exponentially with images that consist mainly of texture. Based on the simulation results, small perturbations – two or three pixels – produced the largest reduction in the PSNR value. However, the percentages of visual errors were more affected by the frequency of perturbations than by the magnitude of perturbations.

Although there was deterioration in the quality of virtual images that were created by using estimated disparity fields, these new intermediate images are perceived by the human eye as realistic. These results were obtained by using two low-complexity algorithms: a bidirectional local maximisation algorithm for disparity estimations and an intermediate image interpolation technique for creating virtual images. An important issue is the identification of areas of occlusion.

There is much scope for further research in this area. A strategy for detection of outliers using object information is required. Therefore, one line of future research will be to develop an error measure for the evaluation of the fundamental matrix estimation that provides a measure of scene geometry representation. Another direction will be to incorporate the meaning of the correlation score – quantity and sign – in the identification of occlusion areas and areas of discontinuity. Investigation is also required into the structure of spatial variability in correlation windows. This could be attempted using a Markov-Bayes model. Research is also required on the numerical stability of the system of linear equations used by Affine and Euclidean image synthesis.
As the biggest library if it is in disorder is not as useful as a small but well-arranged one, so you may accumulate a vast amount of knowledge but it will be of far less value than a much smaller amount if you have not thought it over for yourself.

(Arthur Schopenhauer)

REFERENCES


References


Ber1889 Bertrand J. Calcul des probabilities. Gauthier-Villars, Paris, 1889


pp. 425-445


CMU  http://www-2.cs.cmu.edu/afs/cs.cmu.edu/project/cil/ftp/


References


Cre1993  Cressie N. Satatistics for Spatial Data. John Wiley and Sons, 1993


References

Applications. INRIA Sophia-Antipolis RR-2013, 1993, 49 pages


Gal1885 Galton F. Regression Towards Mediocrity in Hereditary Stature. In Journal of the Anthropological Institute, No. 15, 1885, pp. 246-263


<table>
<thead>
<tr>
<th>Reference</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Had1923</td>
<td>Hadamard J. Lectures on Cauchy’s Problem. Yale University Press, New Haven, 1923</td>
</tr>
</tbody>
</table>
References


Izq2002b Izquierdo E., "Using Invariant Image Features for Synchronization in...

Izq2002c Izquierdo E., Ghanbari M., "Key Components for an Advanced Segmentation System", IEEE Transactions on Multimedia, Volume 4, Issue 1, Pages 97-113


A Computational Framework for Stereo Imaging
References

Ken1938  Kendal M. G. A New Measure of Rank Correlation. Biometrika, Vol. 30, No. 1/2, 1938, pp. 81-93


Kop1983  Kopydlois D. 100% inspection of crossbars using machine vision. Publication MS83-210, Society of Manufacturing Engineers, Dearborn, MI, 1983


<table>
<thead>
<tr>
<th>Reference Code</th>
<th>Reference Details</th>
</tr>
</thead>
</table>
Biometrika, Vol. 11, No. 3, 1916, pp. 231-238


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*A Computational Framework for Stereo Imaging*
References


### References

<table>
<thead>
<tr>
<th>Reference Code</th>
<th>Author(s)</th>
<th>Title</th>
<th>Conference/Volume</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tru1999</td>
<td>Trucco E., A. Fusiello, and V. Roberto.</td>
<td>Robust Motion and Correspondence of Noisy 3-D Point Sets with Missing Data.</td>
<td>ELSEVIER Pattern Recognition Letters, Vol. 20, 1999</td>
<td>pp. 889-898</td>
</tr>
<tr>
<td>Tru2003b</td>
<td>M. Trujillo &amp; E. Izquierdo, &quot;Robust Estimation of the Fundamental Matrix by Exploiting Disparity Redundancies&quot;, 3rd IASTED International Conference on Visualization, Imaging and Image</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
References


Tru2004b M. Trujillo and E. Izquierdo, “A Robust Correlation Measure for the Correspondence Estimation”, IEEE in cooperation with Eurographics and ACM SIGGRAPH, the second International Symposium on 3DPVT (3D Data Processing, Visualization, and Transmission) Greece, 2004


Tuk1977 Tukey, J. Exploratory Data Analysis. Addison-Wesley, 1977


<table>
<thead>
<tr>
<th>Reference</th>
<th>Title</th>
<th>Details</th>
</tr>
</thead>
</table>
References


