14th International Machine Vision and Image Processing Conference

14th International Machine Vision and Image Processing Conference: IMVIP 2010

Edited by

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CAMBRIDGE SCHOLARS
PUBLISHING

14th International Machine Vision and Image Processing Conference:
IMVIP 2010,
Edited by Martin J. Leahy and Marie-Louise O'Connell

This book first published 2011

Cambridge Scholars Publishing

12 Back Chapman Street, Newcastle upon Tyne, NE6 2XX, UK

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN (10): 1-4438-2962-5, ISBN (13): 978-1-4438-2962-5

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FOREWORD

On behalf of the organizing committee of the 2010 International Machine Vision and Image Processing Conference (IMVIP 2010) we extend a *céad míle fáilte* – a hundred thousand welcomes – to all speakers and delegates. The University of Limerick, Ireland was proud to host this years event organized under the auspices of the Department of Physics and Energy.

This year marks the fourteenth in a series of IMVIP conferences that have provided a vital platform for communication and exchange between academics and industrialists from the numerous related disciplines involved in the processing of image based information over the last 14 years. These proceedings provide an overview of the 14th IMVIP conference presenting papers which reflect critical research within the field.

All papers submitted for presentation were evaluated and reviewed by our program committee members. Individuals whose papers were chosen for presentation at the conference submitted manuscripts to be published in these proceedings. The author of the paper with the highest score from the reviewers received the "Best Paper Award" at the conference.

We would like to thank all those who submitted papers for review and those who provided manuscripts for publication in these proceedings. We extend a special thanks to our reviewers and local organizers, whose effort and hard work reflect their commitment and dedication to the profession. We are grateful to our keynote speaker; Prof Joachim Weickert of the Mathematical Image Analysis Group at Saarland University in Saarbruecken, Germany for taking time out to present at our conference this year.

IMVIP 2010 was run in association with the Irish Pattern recognition and Classification Society (IPRCS), a member organization of the International Association of Patten Recognition (IAPR).

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STEREO MOTION AND OPTICAL FLOW

Stereo Images for 3D Face Applications: A Literature Review

Claudia Arellano and Rozenn Dahyot[1]

Abstract

Stereo cameras are becoming increasingly available to customers at a more moderate cost. It is expected that this will impact upon face recognition processes used in applications such as indexing and retrieval in personal picture databases. In this paper we propose a review of the different techniques used for 3D face recognition and reconstruction. We emphasize the tendencies of both fields and how they have been integrated to allow new applications.

1. Introduction

Face recognition has been a very active research area during the last two decades, mainly for its potential in commercial and law enforcement applications. Most of the research in the early years has been done using 2D images but now, modern approaches aim at performing 3D face recognition. Indeed 3D modelling helps in dealing with variations in pose and illumination that are tricky to deal with in uncontrolled environments using only 2D images.

Figure 1 illustrates a three step face recognition system. First, data capture can be performed using laser scanners (which is one of the most accurate systems to acquire a dense 3D model but it requires a long exposure time, cooperation from the individual and remains too expensive a tool to enjoy widespread use), structured light technology (faster and cheaper but less accurate and contains more missing data), and multiple view reconstruction of the 3D face by using two or more 2D images. Stereo images are a very attractive alternative for 3D face reconstruction since this is a cheap, fast and passive data acquisition system. Dedicated

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stereo recording hardware such as the 3D FinePix camera and the Minoru webcam are already available to consumers. This suggests that there is a market for developing applications for stereo images for example, in editing, indexing and retrieval in personal stereo images libraries.

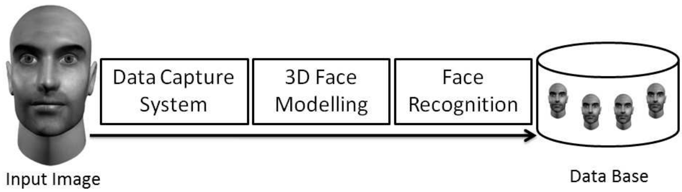

Figure 1. 3D Face Recognition Process

The contributions of this paper are to update previous literature reviews in 3D recognition performed up to 2007 [Abate2007, Gupta2007], explore the state of the art of stereo face reconstruction and to present a brief review of stereo applications over 3D face recognition. Section 2 is dedicated to stereo face reconstruction, while section 3 is a general review of 3D face recognition techniques. Finally section 4 presents some conclusions and open problems.

2. Stereo Face Reconstruction

3D Face reconstruction from 2D images has been explored using different approaches such as analysis by synthesis [Patel2009] and shape from: shading, texture, motion [DeCarlo2000] and stereo among others.

Stereo face reconstruction is not a trivial problem, since the calculation of the disparity map using conventional correlation based methods is very sensitive to the image texture and face is an almost textureless object. Lighting conditions and occlusions in the scene can also increase the complexity of stereo matching. To overcome these difficulties, two different approaches have been explored: adding prior information through geometrical constraints during the matching process and/or using post-processing techniques to improve the estimated shape of the face.

Methods of shape from shading and analysis by synthesis have improved thanks to using stereo images [Zhang1999]. Since shape from shading works well over textureless objects, it has been integrated into stereo algorithms [Fua1995, Samaras2000]. Cryer *et al.* for instance proposed a technique that integrates the high-frequency information from the shape from shading and the low frequency information from stereo

[Cryer1993, Cryer1995]. On the other hand, Lengagne *et al.* [Lengagne1996] use shape from shading constraints to generate the 3D face model during the matching process. Mixing concept from analysis by synthesis, Lengagne *et al.* [Lengagne2000] also propose the inclusion of a prior to help the reconstruction process by adding the differential information about the object shape and by constraining curvature values and crest lines. However, the overall process is performed at high computational cost.

Sung *et al.* propose an estimation of the facial shape and its motion using Stereo Active Appearance Model (STAAM) [Sung2006]. The computational efficiency is improved thanks to thin spline representation of the face which allowed Ionita *et al.* to propose a real time application for gaming [Ionita2009].

Zheng *et al.* propose the use of a 3D generic face as intermedium for correspondence, fitting each stereo image to the reference 3D face to synthesize a unique pose and estimate the depth map [Zheng2007]. Other analysis by synthesis approaches that include texture information over the reconstruction process have been explored by Morency *et al.* [Morency2002] and Romeiro *et al.* [Romeiro2007] respectively. For instance Romeiro *et al.* include a prior 3D Morphable model in shape and texture in the minimization cost function for the stereo matching, demonstrating the advantage of using texture information to deal with occlusions. Inclusion of prior information about face shape and texture improves performance of stereo reconstruction, but the accuracy of the recovered shape is inversely proportional to the computational speed. Performance of the recognition algorithm is directly related to the 3D shape representation as outlined in the following section.

3. 3D Face Recognition Techniques

The appearance of a face is described by its 3D shape and its albedo map, suggesting that, to overcome problems due to illumination, pose and expression variations, all the 3D face information should be used.

During the last decade several techniques in 3D recognition systems have been proposed as reported in the surveys by Kittler *et al.* [Kittler2005], Scheenstra *et al.* [Scheenstra2005], Bronstein *et al.* [Bronstein2005] and Abate *et al.* [Abate2007]. A more recent review written in 2007 by Gupta *et al.* [Gupta2007] classifies 3D recognition algorithms in two categories; appearance based and `free form' based algorithms (Figure 2). We follow the same structure as Gupta *et al.* to review the most representative techniques in 3D face recognition including the new approaches that have been proposed since 2007. In order to emphasize the role of stereo images in 3D face recognition application, this section is divided into two parts, general approaches are presented in the first part, while the second focuses on 3D recognition methods using stereo images.

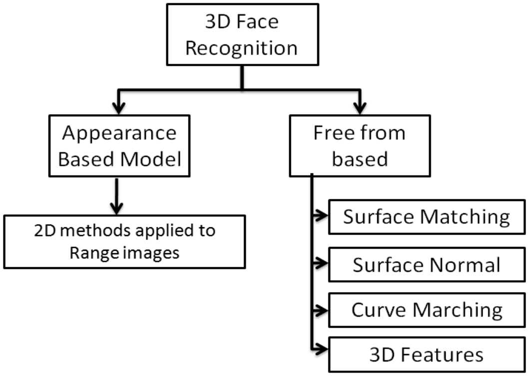

Figure 2. 3D Face Recognition algorithm classification [Gupta2007].

3.1. General algorithms for 3D Face Recognition

3D objects can be represented as a point cloud, a mesh grid or a range image. Range images (also known as 2,5D Images) are 2D images in which the depth information is encoded directly in the 2D image by replacing the intensity values with the depth value, so that the new pixel value corresponds to the surface geometry of the object.

3.1.1. Appearance Based Models

Appearance based techniques use range images with traditional 2D recognition methods. The most common approaches are Principal Component Analysis (PCA), Linear Discriminant Analysis (LDA), Hidden Markov Models (HMM) among others. Whilst comparisons of using range images over 2D intensity alone have not shown sufficient evidence to classify them as better, there is a consensus that performance under pose variation is less affected in range image approaches making it more robust in such conditions.

3.1.2. 'Free form' Based Models

3D face Recognition algorithms using `free form' models over point cloud and mesh representations have been explored in four main ways: Surface Matching, Surface Normal, Curve (or profile) Matching and Features classifications.

Surface based methods consist of comparing two face surfaces using a suitable metric after the registration and normalization of each surface. Hausdorff distance or Mean Square Errors are often used as similarity metrics. For registration, the Iterative Closest Point algorithm (ICP) is the most widely used algorithm [Amor2006, Besl1992, Cook2004]. Many variations and improvements of this algorithm have been proposed to overcome its sensitivity to noise and outliers when it is applied for face recognition. Weiwei *et al*. [Weiwei2009] have improved its robustness by using M-estimators. However their algorithm has difficulties in dealing with non rigid objects because it is based mainly on geometrical constraints. Lu *et al*. [Lu2005] introduce another modification by using thin plate spline (TPS) model to represent the non-rigid deformation reporting better performance over faces with varying facial expressions.

Amberg *et al*. [Amberg2008] uses a morphable model to fit the 3D face data through a non rigid ICP algorithm. The recognition step can be done either by comparing the face surface directly or by using the parameters of the morphable model obtained.

Surface normal has been used to define statistical models in describing facial shape and using it as a signature for face recognition. Some examples of these methods have been proposed by Smith at al. [Smith2005] and Tanaka *et al*. [Tanaka1996].

Curve matching recognition methods are based on the hypothesis that using the whole face surface is not necessary for recognition. Using just a few curves extracted from the facial surface can be enough to perform recognition, especially when the central vertical profile is used [Liposcak1999, Pan2005, Haar2008]. Combining curves with contour, Chao Li *et al*. [Li2005] report comparable results to those using Principal Component Analysis on 2,5D range images.

Several approaches using local and global features can also be found in the literature [Gunlu2009, Tang2009, Yunqi2009]. For example Gunlu *et al*. [Gunlu2009] present a feature extracted by the 3D discrete cosine transform (DCT) and Fourier Transform: the feature vector is composed by the most discriminative 3D transform coefficients. Using the nearest neighbour as classifier allows recognition rates above 99%. Lei Yunqi *et al*. [Yunqi2009] recently proposed a feature representation of face based on surface classification Image (SCI). The SCI is obtained from the calculation of the Gaussian and mean curvature at each point of the face surface, and classifying them according to a gray scale intensity level. The recognition process is performed using the SCI as input for a PCA method and achieves better results than just applying PCA over the depth face image.

Even though most of the 3D recognition methods report performance of over 95% (on neutral expression) there is no comparison in the literature that allows us to establish some degree of real ranking or objective performance. Most of the experiments were carried out on different databases, and recorded under various conditions. It is strongly demonstrated however that 3D face representations improve results of 2D techniques when they are used in combination and also that 3D recognition methods perform better under pose variation conditions since the pose can be corrected before performing recognition [Bowyer2006]. In the last few years most of the focus has been in dealing with facial expression variation, some approaches addressing this problem can be found in Lu *et al*. [Lu2005] and Chang *et al*. [Chang2005], but this is still an open problem. For instance, Chang *et al*. perform recognition over regions that are only barely affected by facial expression, obtaining a recognition rate of 87%, which suggests that there is still room for improvement.

3.2. Stereo based 3D Face recognition algorithms

Stereo information increases face recognition rates for human perception especially under transformation in perspective between the training and test image [Liu2005]. In this section we explore stereo based algorithms for face recognition in 3D performed by machines, following the same structure than the previous section.

3.2.1. Appearance Based Models

Wang *et al*. [Wang2006, Wang2007] use stereo images for the generation of range images and recognition is performed using 2D Fisher Discriminant Analysis trained separately on depth information and intensity appearance. The best match corresponds to the minimum sum of the weighted discriminant Euclidean distance. Results show recognition rates of 95% when the algorithm is tested over a set of frontal view images (while using appearance or depth image separately, results are only 81% and 87% respectively).

Samanai *et al*. [Samani2006] also explore the combination of depth information and appearance image to improve recognition but using Principal Component Analysis over the disparity map and intensity values concatenated together in one feature vector. Results show a recognition rate of only 62% but the database used for testing includes pose, expression and illumination variations which make it more challenging.

3.2.2. 'Free form' Based Models

Hayasaka *et al*. [Hayasaka2006] propose a phase-based matching algorithm to find the correspondence in between the stereo pair using the information given by the 2D Fourier transform. To improve accuracy, they define an analytical function to estimate the sub pixel position of the correlation peak. The effects of the periodicity of the Fourier transform are avoided by using a windowing technique while a Gaussian filter is used to eliminate aliasing and noise [Uchida2005]. Surface registration is then performed using the ICP algorithm and the recognition is performed by taking the distance between the two facial data.

Fransens *et al*. [Fransens2005] use a morphable face model (shape and texture) taken from a set of 3D training images obtained with a laser scan. This model is used as a constraint during the minimization process of the stereo matching for both shape and texture (it can also be interpreted as prior information over the shape that is being reconstructed from the stereo pair). The face model parameters (for shape and texture) represent the feature vector to be compared with the database for recognition. Experiments were performed under different pose and lighting conditions, indicating that recognition rates increase by using shape and appearance together (compared with the same methods but using the shape feature vector or the texture vector alone), but the performance decreases when the orientation of the face is far from the frontal view.

Wu *et al*. [Wu2008] on the other hand generate the depth map by searching correspondence locally (divide the face in 5 regions according to its main features: eyes, mouth and nose) and matching it in the neighbourhood by cross correlation of image intensity over two pixel patched centred in each feature. The recognition method consists in the extraction of different features such as point cloud, surface normal, facial profile and PCA of depth image and merged them using a rank-based decision level fusion algorithm.

Rara *et al*. [Rara2009] investigate a recognition technique for subjects located at different distances (3, 15 and 33 meters) from the camera. A feature detection method is used for finding the eyes, nose and mouth centers to initialize an active appearance model and fitting it through an inverse compositional image alignment algorithm (ICIA). The minimization of the error between the input images wrapped to a generic face mesh and the appearance model is performed to get the 3D face vertices. For recognition four methods are tested: feature vector computed with PCA on the 3D vertices; a goodness-of-fit criterion (after rigidly registering the 3D vertices of both images); feature vector from PCA of x-y plane projections of the 3D vertices and finally the goodness-of-fit criterion also in the x-y plane projections of the 3D vertices (after frontal pose normalization). Recognition performances using the x-y projection of the vertices report to be better and more stable to position variations than those based on the 3D vertices mesh.

Table 1 shows a summary with the key components of the methods described above, namely: the stereo matching algorithm used, the recognition technique, the database where the approaches were tested and their results. It is not possible to compare the results directly since experiments were conducted upon different database. Not only variations in pose, illumination, occlusion or facial expression in the database affect the performance, but also the quantity of images in the database and the presence/absence of impostor faces. With the exception of Wang *et al.*, [Wang2006], most stereo algorithms for face recognition use some prior information during the matching process or some specific constraints to restrict the area for searching correspondence.

3.2.3. Other approaches using stereo algorithms

Other approaches for face recognition that use stereo algorithms can be also found in literature. For instance trinocular stereo systems (3 images) have been reported by Lao *et al.* [Lao2000] and Chiba *et al.* [Chiba2004].

Lao *et al.* [Lao2000] propose the use of a modified segmented stereo based algorithm where the searching space is reduced by restricting it to isoluminance lines of the same intensity. To detect the pose and align the 3D model obtained from the stereo system an iris model is used to find its position and, using geometry, the angle of the face with respect to the frontal view is estimated. Once the 3D model is aligned to the frontal view the recognition process is performed by calculating the minimum distances between the face model and the database. Even though the algorithm does not generate a dense depth map of the face, it shows recognition rates above 90% when tested with different poses and illumination conditions.

Author	Stereo Algorithm	Recognition Algorithm	Database Characteristics					Results
			Exp.	Ilum.	Pose	Occlu	N^0 Subj./ Imag.	%
Wang [47]		2D Fisher LDA	No	No	No	No	106/848	95
Samani [37]	Wavelet based algorithm [28]	PCA	Yes	Yes	Yes	Yes	22/1080	62.59
Hayasaka [18]	Phase-based algorithm [30]	ICP (Point to plane distance)	No	No	No	No	22/220(5775)* *Impostor	N/R
Fransens [14]	Stereo matching using Morphable Models (texture and shape)	Feature Vector (model parameters)	No	No	Yes	No	70/700	$82 - 100$
Wu [50]	Cross Correlation	Feature vector					300	96.2
Rara [35, 34]	Stereo AAM	PCA and goodness-of-fit criterion	No	No	No	No	30(3 meters)	100
			No	No	No	No	30(15 meters)	90
			No	No	No	No	30(33 meters)	85

Table 1. Summary of the stereo face recognition approaches.

Chiba *et al*. [Chiba2004] applied feature matching recognition using a 3D face mesh as feature vector. Results are based on a very small dataset.

of images (10 subjects) where effects of pose and illumination variations are investigated.

Papatheodorou *et al.* [Papatheodorou2005] create a PCA model for recognition based in a trinocular data capture system. The shape recovered is registered to a standard template using the ICP algorithm and normalized by a B-spline approximation where a sphere is deformed into the face surface.

A novel approach using stereo for face recognition was recently proposed by Castillo *et al.* [Castillo2009]. Most reported previous works focused on recording images to reconstruct a 3D model. Castillo *et al.* realize that stereo correspondence algorithms can also be used as a measure of similarity between images: instead of performing explicitly 3D reconstruction, they use stereo matching techniques to compare two different images. This method proves to be invariant to pose variations (angle), since they calculate the epipolar constraints between the two images and defined the corresponding cost matching function.

4. Conclusions

It is clear from the literature reviewed that 3D face information improves recognition rates in pose variant environments. The main advantage of using stereo for 3D face reconstruction over using scanners is the viability for developing applications where no cooperation from the customer is needed, but there is still work to be done in terms of accuracy of the recognition methods. The use of multiple sources of information (e.g. inclusion of prior information such as shape model, morphable models or geometrical constrains) are leading to better results but challenges in dealing efficiently with lighting and expression variations remain.

5. Acknowledgments

This research is supported by Trinity College of Dublin (postgraduate Scholarship) and Government of Chile.

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3D OPTICAL FLOW FROM SINGLE AND DUAL DOPPLER RADARS

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Abstract

We present a 3D Optical Flow application using a regularization method to recover 3D wind velocity quantitatively from synthetic data and qualitatively from real data for both single and dual 3D Doppler Radars. By dual Doppler data we mean data from 2 separate but overlapping Doppler radars (the area of overlap is known from geometry to be a lens). Our algorithm easily extends to multi-radars but we do not have any real data corresponding to this case. Our algorithm regularizes terms consisting of a radial velocity constraint, a local velocity smoothness constraint and a least squares consistency constraint. We describe how we generated "realistic" synthetic data for our experiments and we give several error metrics we use in our quantitative error analysis. We also present 3D optical flow results for the overlapping Doppler data from radar stations in Detroit and Cleveland. We demonstrate that optical flow calculated by regularization from dual radars is quantitatively and qualitatively better than optical flow calculated from single radars and that regularization is better than least squares for both single and dual radars.

1. Introduction

Doppler radar is an important meteorological observation tool for detecting and tracking severe weather phenomena. Much research has been devoted to retrieving 3D full velocity from the observed radial velocity

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(Lhermitte and Atlas [Lhermitte1961], Easterbrook [Easterbrook1975] and Waldteufel and Corbin [Waldteufel1979]).

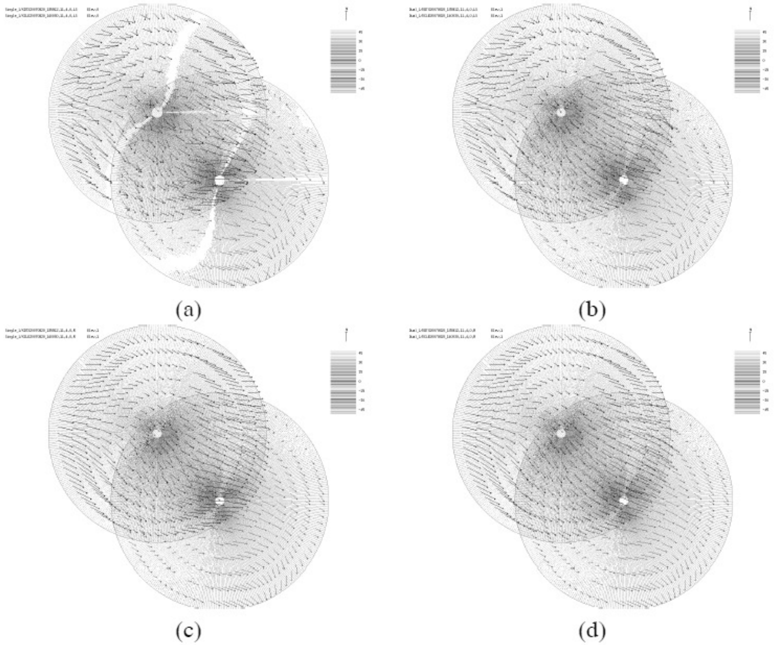

Figure 1. The (a) single and the (b) dual least squares UV flow fields and the (c) single and the dual regularized UV flow fields for variation level K = 5 and 20% noise for then $\vec{V}_{Base2} = (20,10,5)$ synthetic data.

Little quantitative analysis of this work is available (and there is no common test data used or available) making comparisons difficult.

Rather than using the traditional methods provided by meteorologists, our research team is using the 3D Optical Flow framework ([Barron2005]) to measure 3D velocity. 3D optical flow (3D velocity) is a simple extension of 2D optical flow. We have already demonstrated a Horn and Schunck like least squares regularization calculation [Horn1981] that uses a least squares constraint [Lucas1981] on real data from a single Doppler radar NEXRADI dataset [Chen2001, Barron2005]. Both NEXRADI and NEXRADII (used here) Doppler datasets consist of number (15-16) of cones of data where each cone wall has a different but constant angle (0° to