images used. In the present work we can determine several points matching between the two images which allow us to have more self-calibration equations.

The system (20) contains non- linear equations to solve it we minimize the following cost function:

$$\min_{\psi_{ij}} \sum_{i=1}^{r-1} \sum_{j=i+1}^{r} \sum_{h=1}^{d} (\rho_{ijh}^2 + \sigma_{ijh}^2) \qquad (21)$$

The minimization of the cost function (21) is performed by using the algorithm of Levenberg-Marquardt [29].
With r is the number of images used, d is the number of matching points between the two images used and :

- Ψ_{ij} is the vector of the intrinsic parameters of the camera in both views .
- $\rho_{ij\,h}$ and $\sigma_{ij\,h}$ are given by:

$$\rho_{ijh} = f_{h11i} f_{h12j} - f_{h11j} f_{h12i}$$
$$\sigma_{ijh} = f_{h11i} f_{h12j} - f_{h11j} f_{h12i}$$

The algorithm of Levenberg-Marquardt requires an initialization step . Assume for this purpose that the following conditions are satisfied:

- The principal point is in the center of the image so u_{0i}, v_{0i} , u_{0j} and v_{0j} are known.
- The pixels are squares so $\varepsilon_i = \varepsilon_j = 1$ and $\tau_i = \tau_j = 0$.
- By replacing the above parameters by their values in the system (20) we can estimate g_i and g_j .

5 Experimental evaluations

To evaluate the robustness of our approach two types of data are used: synthetic and real.

5.1 Computer simulations

In this simulation two 512x512 images of a planar scene is considered. After the detection of the interest points by using the Harris detector [30] and determining the matching points between the two images by using the correlation measure ZNCC [31,32,33,34,35], the inter-images homographies are estimated. The projection points of the scene in the image planes permit to formulate linear equations whose solutions are used with image of absolute conic in both views (see equations (18) and (19)) to obtain a system of non-linear equations from which we obtain a non-linear cost function, the resolution of the latter is given by performing a minimization using algorithm of Levenberg-Marquardt. The estimation of the elements of the matrix of the image of the absolute conic leads to the obtaining of the intrinsic camera parameters in each image. The different algorithms (Harris, ZNCC, Levenberg-Marrquardt, estimation of homography between images) used in this article are implemented by the object oriented programming language that is java.

To test the effectiveness of our algorithm we compared it with two methods. A reliable classical calibration [12] presented by Z. Zhang and another self-calibration method of camera characterized by variable intrinsic parameters [21] developed by Z. Jiang. The choice of the method of Z. Zhang is that it is a calibration method (uses a scene known so it gives very accurate results) which may be considered us a reference to self-calibration methods to test their strength while the choice of the approach of the Z. Jiang can be justified by the fact that this method contains common points with ours whose the main one is the variable intrinsic parameters. The methods are compared in the study of the relative errors in the focal length, the principal point, the scaling factor, the skew factor and the time of calculation, and this according to the number of matching points between the two images.

In this first computer simulation, we begin by studying the influence of the number of matching points between the two images on the calculation time covered by the three methods. To measure the execution time we implemented in our application java a class based on the method currentTimeMillis() of de class System. The following table shows the calculation time taken in seconds (by the three methods).

Table 1. Calculation time in seconds in function of the number of matching points

Number of matching points	Execution time in seconds		
	Our method	**Z.Zhang**	**Z.Jiang**
15	0.6	1.8	3.93
18	1.2	2	4.54
21	2.34	3.76	5.65

24	3.82	4.22	7.86
27	5.2	5.8	8
30	6	7.53	10.30
33	8.15	8.9	12.40
36	10.33	12.68	15
39	12.75	13.80	16.55

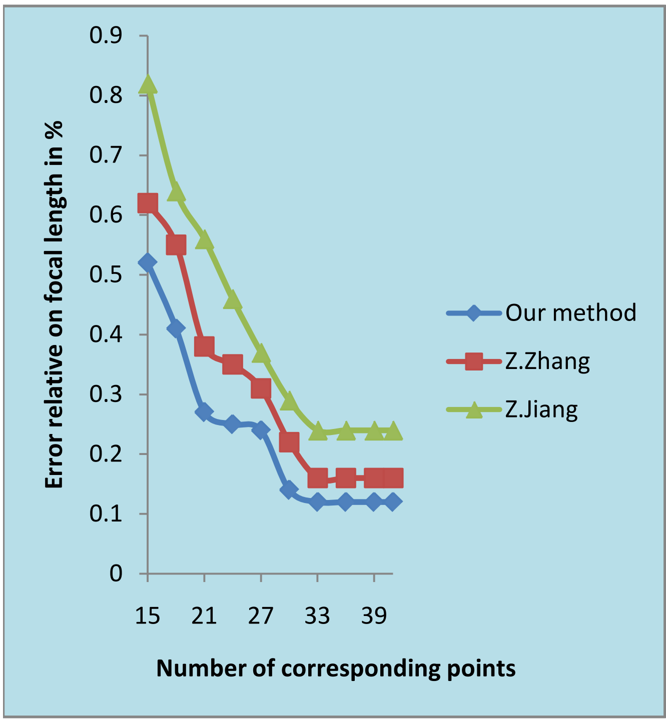
The values showed by the above table show that our method gives the satisfactory results. The growth in the number of matching points between the two images used causes an increase in the number of self-calibration equations on the one hand and the number of iterations performed to estimate the intrinsic parameters of the camera on the other hand; which explains the growth of the execution time for the three method; nevertheless, our method appears faster compared to others and this can be explained by the fact that the method presented by Z.Zhang performs two minimizations: the first to estimate the homography matrix scene to image and the second to determine the intrinsic parameters of the camera. While the approach given by Z.Jiang involves a determination of the coordinates of the plane at infinity and the estimation of the homography matrix of this plane which requires more calculation than our method.

The second half of our simulation tests the influence of the number of the matching points between the two images on the focal length , the principal point , the scale factor and the skew factor by performing a comparison with the methods [12] and [21] (figure 3).

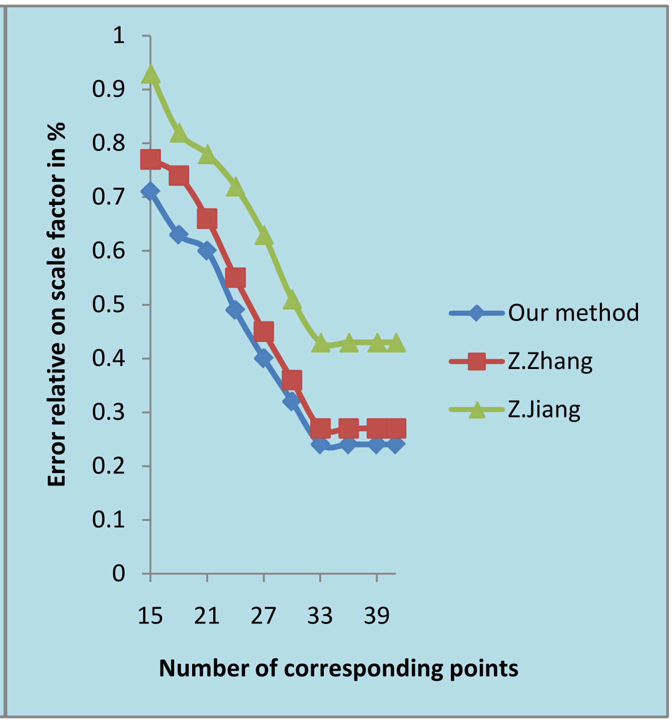
The figure 3 shows that the estimation of the intrinsic parameters of the camera by our method is more accurate than the methods of Z.Jiang and Z.Zhang.This can be explained by the fact that this method uses directly the interest points in the images without finding out the geometric structure of the scene. These interest points are numerous and easy to detect. The above figures show that the relative errors of different intrinsic parameters decrease for a number of matching points between 15 and 33 this can be explained by the fact that the optimal solution of the cost function is not yet reached once the latter is reached the relative errors become constant and this for a number of matching points greater than 33.

5.2 Real images

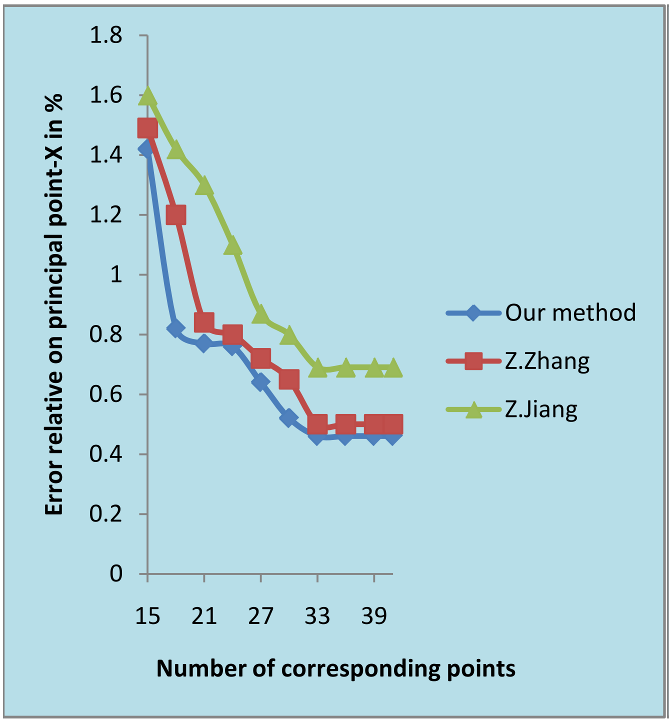
In this real evaluation two images of size 512 × 512 of a real planar scene (to construct the scene used, we placed a cartoonish image on a planar surface see figure 4) are acquired from two different views with a CCD camera having varying intrinsic parameters. The interest points are determined by the Harris detector and



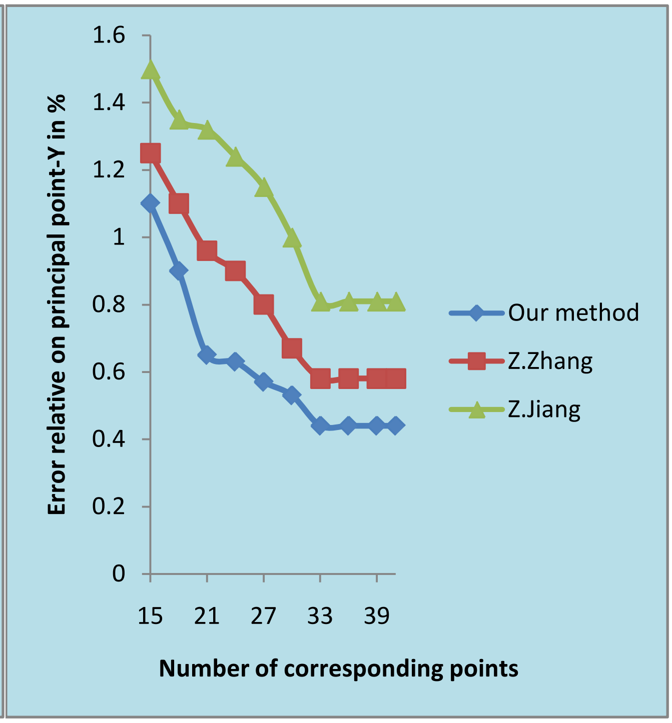
a. Simulation results on focal length



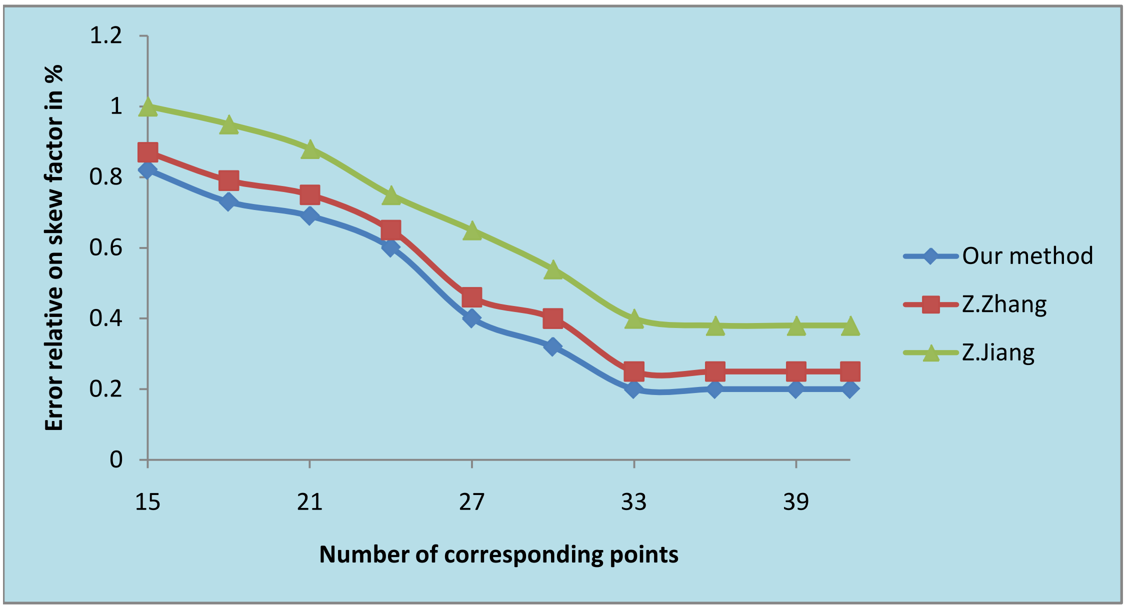
b. Simulation results on scale factor



c. Simulation results on principal point- X



d. Simulation results on principal point – Y



e. Simulation results on skew factor

Fig. 3. Simulation results on the g, ε, τ, u_0 and v_0 according to the number of matching points between the both images

their matching is given by the ZNCC correlation measure then the intrinsic camera parameters are estimated by applying our method proposed in this present article. The interest points in the two images, as reported previously, are detected by using the Harris detector and then are matched by using the ZNCC algorithm (Figure 5).

Estimation of intrinsic camera parameters. This step consists of estimating the intrinsic parameters of the camera in its two positions by applying our

new self-calibration method. The table 2 shows the solution obtained by using our method and those presented by Z.Jiang and Z.Zhang. For clarity we have displayed in table 2 only the results for fifteen and eighteen matching points between the two images *i* and *j*.

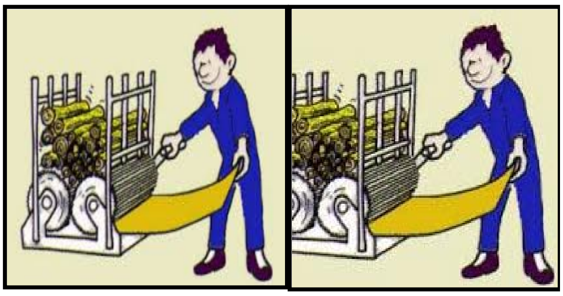
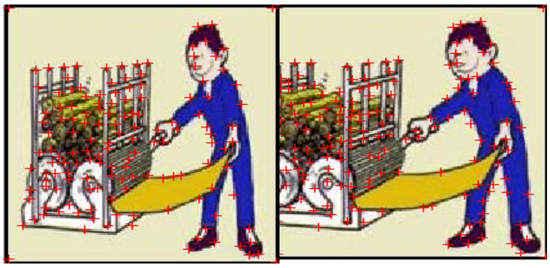
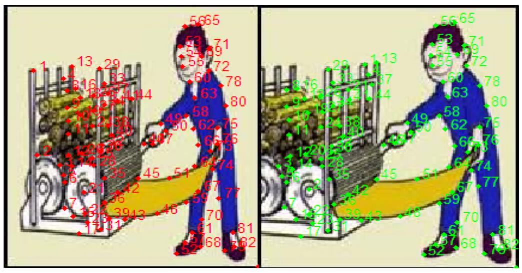


Fig. 4. The two real images used



a. Interest points detected by Harris detector



b. Matching points by ZNCC measure

Fig. 5. Detection and matching of interest points.

As showed in the table 2, the results obtained by our approach are similar to those given by the method of Z.Zhang which justifies the performance of our method (because the calibration methods are reliable) and better than those estimated by the method of Z. Jiang and this by considering the following advantages: our method is capable of self-calibrating a camera which moves freely, with variable intrinsic parameters and by using only two images of a unknown planar scene.

Table 2. Results of the experiment on real data given by the three methods

		Matching points	g	u_0	v_0	τ	ε
Our method	Image i	15	1650	261	258	0 ,08	0,87
		18	1654	262	260	0 ,05	0,90
	Image *j*	15	1652	261	255	0 ,07	0,93
		18	1656	260	259	0 ,04	0,94
Z.Zhang	Image *i*	15	1657	263	259	0,07	0,85
		18	1655	262	260	0,06	0,91
	Image *j*	15	1654	260	261	0,09	0,89
		18	1653	263	261	0,06	0,93
Z.Jiang	Image *i*	15	1636	252	261	0,21	0,65
		18	1635	261	260	0,16	0,74
	Image *j*	15	1637	253	262	0,23	0,68
		18	1638	260	261	0,18	0,76

6 Conclusion

This article proposes a novel algorithm for camera self-calibration in the case of the varying intrinsic parameters. The main point of this work is the possibility of surmounting the constraints of the self-calibration problem, constraints about camera intrinsic parameters, constraints about the scene viewed and constraints about the camera motion. In fact, our present method is capable of self-calibrating a camera having variable intrinsic parameters, from an unknown planar scene and by applying to the camera a free motion. The principle of this new approach treated in this paper, is based on the use of three non-collinear points of the scene that represent the vertices of an unknown parallelogram and its projections into only two images *i* and *j*. The projection of the three non-collinear points of the scene permits us to obtain two equations according to the intrinsic camera parameters and the image of the absolute conic in both images. Since for two images the number of variables representing the intrinsic parameters of the camera is ten so we will need at least ten equations. To solve this problem we have applied to the basic parallelogram a sequence of random transformations consists of translations and rotations to find new parallelograms to obtain more equations. In our future research we will try to improve our approach by reducing the number of matching points used between the two images, in other words by using a single unknown parallelogram of an unknown planar scene. The robustness of our method is proved by experimental results on synthetic and real data.

References:

[1] S. Maybank and O. D. Faugeras, A theory of self-calibration of a moving camera, *Int. Journal of Computer Vision*, 8(2), pp.123–151, August 1992.

[2] O. D. Faugeras, Q. T. Luong, and S. J. Maybank, Camera self-calibration: Theory and experiments, *In G. Sandini, editor,Proc. 2nd European Conf. On Comp Vision, Lecture Notes in Comp. Science 588, Springer–Verlag*, pp. 321–334, May 1992.

[3] N. El Akkad, M. Merras, A. Saaidi and K. Satori, Camera self-Calibration with Varying Parameters from Two views, *Wseas Ttransactions on Information Science and Applications*, Vol. 10,No.11, 2013.

[4] M. Merras, N. El Akkad, A. Saaidi and K. Satori, Camera Calibration with Varying Parameters Based On Improved Genetic Algorithm, *Wseas Transactions on Computers*, Vol. 13, 2014.

[5] A.Saaidi, A.Halli, H.Tairi, K.Satori, Self-calibration using a particular motion of camera, *WSEAS Transactions on. Computer*, Res. 3(5), pp. 295–299, 2008.

[6] E.Hemayed, A Survey of Camera Self-Calibration, *In Proceedings of the IEEE Conference on AVSS*, 2003.

[7] P.Sturm and S.J.Maybank, On Plane-Based Camera Calibration: A General Algorithm, Singularities, Applications, *In Proceedings of the CVPR-IEEE*, Vol. 1, pp. 432-437, 1999.

[8] P.Sturm, A case against Kruppa's equations for camera self-calibration, *IEEE Trans. Pattern Anal. Mach. Intell*, Vol.22, pp.1199–1204, 2000.

[9] A.Baataoui, I.El batteoui, A.Saaidi , K.Satori, Camera self-calibration by an equilateral triangle, *Int. J. Comput*, pp.29–34 , 2012.

[10] B. Triggs, Autocalibration from Planar Scenes, *In European Conference on Computer Vision*, Vol.2, pp. 89–105.Friburg, juin 1998.

[11] R. Hartley and A. Zisserman, Multiple View Geometry. *Second edition. Cambridge University Press*, 2003.

[12] Z.Zhang, A Flexible New Technique for camera Calibration, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 22, No.17, pp. 1730-1734, 2000.

[13] B.Triggs, Autocalibration from planar sequences, *In Proceedings of 5th European Conference on Computer Vision*, Freiburg, Allemagne, Juin 1999.

[14] I.EL Batteoui, A.Saaidi and K. Satori, Efficient planar self-calibration of a stationary camera with variable intrinsic parameters, *JATIT*, Vol. 50 No.1, April 2013.

[15] P.Sturm, Critical motion sequences for the self-calibration of cameras and stereo systems with variable focal length, *Image Vis. Computer*,Vol. 20, pp.415–426 ,2002.

[16] Y.Zhang and Q.Ji, Camera Calibration with Genetic Algorithms, *Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions on*, Vol.31, No. 2, 2001.

[17] A. Saaidi, A. Halli, H. Tairi and K. Satori , Self Calibration Using a Planar Scene and Parallelogram, *ICGST-GVIP*, ISSN 1697 399X, February 2009.

[18] X. Cao and al, Self-calibration from turntable sequences in presence of zoom and focus, *Computer Vision and Image Understanding* Vol.102,No.3,pp.227-237,June 2006.

[19] N. El Akkad, M. Merras, A.Saaidi and K.Satori, Camera self-calibration with varying intrinsic parameters by an unknown three dimensional scene, *Visual Computer*, vol.30,No.5,pp.519-530,May 2014.

[20] S. Szénási, Z. Vámossy, M. Kozlovszky, Evaluation and comparison of cell nuclei detection algorithms, *16th International Conference on Intelligent Engineering Systems (INES 2012)*, Lisbon, 2012, pp. 469-475.

[21] Z. Jiang, Self-calibration of Varying Internal Camera Parameters Algorithm Based on Quasi-affine Reconstruction, *Journal of Computers*, Vol. 7, No. 3, March 2012.

[22] Y.Gao, H.Radha, A multistage camera self-calibration algorithm, *In proceeding of IEEE*

International Conference On Acoustics, Speech and signal processing, pp.537-540,2004.

[23] Z.Jiang and S.Liu, The Self-calibration of Varying Internal Camera Parameters Based on Image of Dual Absolute Quadric Transformation, *Information and Automation, Communications in Computer and Information Science, Springer*, Vol.86, pp. 452-461, 2011.

[24] A.Hehden and K.Astrom, Euclidean Reconstruction from Images Sequences with Varying and unknown focal length and Principal Point, *Proc.IEEE CVPR*, pp.438-443, 1997.

[25] Y.Shang, Z.Yue, M.Chen and Q.Song, A new method of camera-self-calibration based on relative lengths, *Information Technology Journal* ,Vol.11,No.3,pp.376-379, 2012.

[26] L.Agapito, E.Hayman and I.Reid, Self-calibration of rotating and zooming camera, *In International Journal of Computer Vision*, pp.107-127,2001 .

[27] M. Pollefeys, R.Koch and L.Van Gool, Self-calibration and metric reconstruction in spite of varying and unknown intrinsic camera parameters, *Int . Journal of Computer Vision*, Vol.32, No.1, pp.7-25, August 99.

[28] R.Paulo, S.Mendonca and R. Cipolla, A Simple Technique for Self-Calibration, *Computer Vision and Pattern Recognition. IEEE Computer Society Conference*, 23 -25 Jun 1999.

[29] J.More, The levenberg-marquardt algorithm, implementation and theory, *In G.A.Watson, editor, Numerical Analysis, Lecture Notes in Mathematics 630. Springer-Verlag*, 1977.

[30] C.Harris and M.Stephens, A combined Corner and Edge Detector, *4th Alvey vision Conference*. pp. 147-151, 1988.

[31] L.Di Stefano, S.Mattoccia and F.Tombari, An Algorithm for Efficient and Exhaustive Template Matching, *In Image Analysis and Recognition,Springer*,Vol.3211, pp. 408–415, 2004.

[32] L. Di Stefano, S.Mattoccia and F.Tombari, ZNCC-based template matching using bounded partial correlation, *In Pattern Recognition Letters, Elsevier*, Vol.26, No.14, pp. 2129–2134, October 2005.

[33] S.Mattoccia, F.Tombari and L. Di Stefano, Reliable rejection of mismatching candidates for efficient ZNCC template matching, *In Image Processing, 2008. ICIP 2008. 15th IEEE International Conference*, 2008.

[34] L.Pei, LiaoNing and Z.Xie, Fast normalized cross-correlation image matching based on multiscale edge information ,*CASM*,Vol.10, Oct 2010.

[35] C.Saravanan and M.Surender, Algorithm for Face Matching Using Normalized Cross-Correlation. *IJEAT*, Vol.2, No.4, April 2013.