Hand Structure Analysis for Finger Identification and Joints Localization

Mujtaba Hassan, Muhammad Haroon Yousaf

ABSTRACT

The development of kinematic model of hand can play a vital role in hand gesture recognition and Human Computer Interaction (HCI) applications. This paper proposes an algorithm for finger identification and joints localization, thus generating the kinematic model of human hand by means of image processing techniques. Skin tone analysis and background subtraction is carried out for hand detection in the workspace. Geometric features of hand are used for hand identification (left or right), finger identification and joints localization. Proposed algorithm is tested for diverse hand poses and remarkable results are produced. Algorithm not only generates the kinematic model for the different orientations of the hand but also have very low computational cost.[1]

Index Terms — Gesture Recognition, Hand Kinematic model, Finger detection, Joints Localization.

KEYWORDS – smart grid, renewable sources, load patterns, infrastructure, utilities, compatible, sustainable, scenarios.

I. INTRODUCTION

The hand has always been of significant importance to humans. In everyday life many interactions are performed by hand including object grasping, message conveying, and numerous other tasks. Keyboard and mouse are currently the main interfaces between man and computer. In recent years, the application of hand gesture has become an important element in the domain of Human Computer Interaction (HCI) [1, 2, and 3] or Human Machine Interaction.

Two general approaches can be applied to classify and analyze the hand gestures for HCI: contact and non-contact .Contact-based approach consists of mounting a device (usually gloves) to the hand which can capture the poses as hand moves. However there are issues associated with almost all glove - based techniques like portability, high cost, and calibration or low resolution. A detailed analysis and review has been done of glove-based techniques in [4] .The non contact or vision-based techniques are glove-free and can be divided into the three-dimensional (3-D) and the two-dimensional (2-D) approaches. In the 3-D approach, 3-D model of the human hand is developed and the parameters are derived to classify hand gestures. As 3- D hand models are quite complicated, as a consequence such models are computationally extensive which makes real-time classification difficult. Compared with 3-D models, the 2D models are relatively less complex. However, 2-D models are generally used with static hand gestures as they do not contain information regarding hand and finger movement for the classification of complex dynamic hand gestures.

Issues and problems related to 2D vision based hand gesture classification have been discussed, resolved and presented in [5]–[8]

In virtual world, the role of human hand interaction with virtual environment is escalating. A reasonable and precise model of hand may be required to be applied in virtual reality, medical simulation, animation, virtual prototyping, special-effects and games. However, modeling an accurate and realistic virtual human hand has always been a challenging task, as great skills are required since the human hand has a complex shape with many degrees of freedom (DOF)

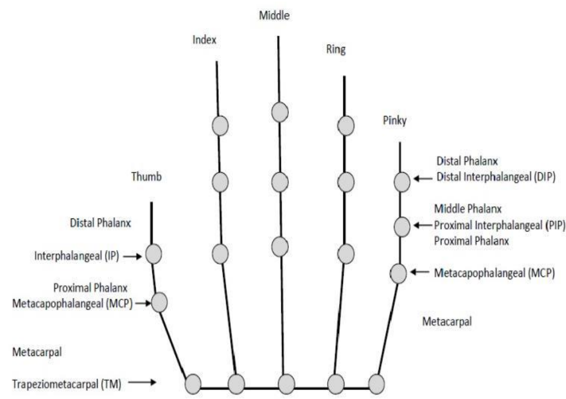

Fig. 1. Kinematic Model of Hand

Fig. 1 represents the kinematic model of hand, which illustrates the naming and localization of fingers and joints. As all ten fingers can take part in producing hand gestures, so these fingers are named according to their anatomical names as pinky, ring, middle, index and thumb. Joints in the human hands are named according to their location on the hand as metacarpophalangeal (MCP), Proximal interphalangeal (PIP) and Distal interphalangeal (DIP). Fig. 1 shows that thumb has only metacarpophalangeal (MCP), interphalangeal (IP) joints.

Many hand models are developed for HCI using vision-based approaches. Rhee et. al. [9] developed a 3D hand model from hand surface anatomy in which hand creases were used to detect hand fingers and joints. Parida et. al. [10] developed hand model for multi-fingered robotic hand in which kinematic modeling and analysis has been done [10]. Wu et. al. [11] contributed in detailed analysis of various hand models.

This paper aims to describe a fast and reliable algorithm, how kinematic model of hand based on 2D vision can be developed. Algorithm helps to identify and tag hand (right or left), hand

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fingers (pinky, ring, middle, index and thumb), finger joints (MCP, PIP and DIP) and finger tips which can be used for the analysis of hand structure. Such kind of hand structure analysis can be utilized in developing hand gesture recognition applications.

II. PROPOSED METHODOLOGY

Proposed algorithm for development of kinematic model of hand is divided into six subunits. Flow chart shown in Fig. 2 presents the brief description of these sub-units. Sub-units are further discussed comprehensively in the subsequent sub-sections.

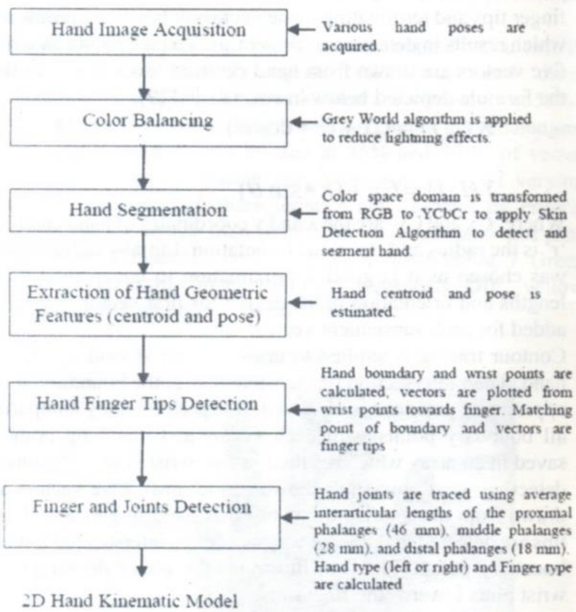


Fig. 2: Flow Chart of Proposed Methodology

A. Hand image Acquisition

Input comprises of image of hand captured in daily life illumination conditions in non-cluttered environment using a CCD/CMOS camera on a flat surface. Fig. 3 (a) shows the image of right hand captured at approximately 90° orientation.

B. Color balancing

Before proceeding to hand segmentation it is necessary to smooth input image in order to reduce the lightning effects imposed by the environment. Grey World Algorithm (GWA) [12] is selected for this purpose. The particular lightning effect can be removed by applying the gray world assumption on the image which results in color image that is very close to original scene. Gray World algorithm is based on the assumption that given an image with sufficient amount of color variations, the average value of the R, G, and B components of the image should be average to a common gray value.

$$R_{avg} = G_{avg} = B_{avg}$$

By scaling α, β and γ in the R, G and B color channels, illuminated color changes can be modeled as mentioned in [13].The algorithm provides solution which is independent of color luminance by dividing each color channel by its average value as shown in the following formula:

$$(\alpha R, \beta G, \gamma B) \rightarrow \left(\frac{\alpha R}{\frac{\alpha}{n}\sum_{i}^{n} R}, \frac{\beta G}{\frac{\beta}{n}\sum_{i}^{n} G}, \frac{\gamma B}{\frac{\gamma}{n}\sum_{i}^{n} B} \right) \quad (1)$$

Fig. 3(b) shows the results after applying Grey World algorithm. Smoothing variation can be observed as compared to original image.

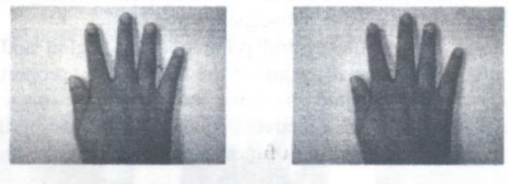


Fig. 3. (a) Input image (b)Input image after color balancing

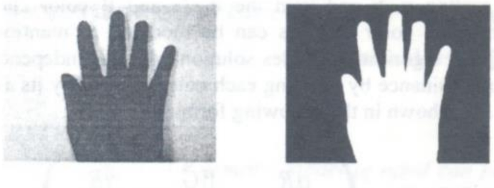
C. Hand Segmentation

Image segmentation and hand detection work as foundation for modeling human hands. Segmentation is essential because it proceeds towards the extraction of the required hand region from the image background. Various algorithms and methods have been proposed to detect and segment visual features like shape, skin color, motion and anatomical models of hands. Performance of various hand segmentation techniques is already discussed in [14].

Detecting hand region in color image is fairly easy as skin color has its own unique property .Many color models exist to detect skin in image e.g. the RGB, HS (Hue, Saturation), normalized RGB and HSV (Hue, Saturation, Value), and YCbCr color spaces were employed in [15], [16], [17] and [18, 19] respectively. As luminance effects skin color so RGB model may impact as false skin color detection. So, YCbCr color model is opted in proposed algorithm to detect skin color in image .The input image after color balancing is transformed from RGB to YCbCr color space and then background is subtracted .A pixel is classified as skin pixel if it falls in certain ranges in YCbCr color space .The ranges are given below.

$$(Cb>=77 \ \& \ Cb<=127 \ \& \ Cr>=133 \ \& \ Cr<=173)$$

The input image is transformed from RGB to YCbCr color space and then all those pixels which fall in above mentioned range of YCbCr color space are denoted as marked pixels by assigning value "1" and unmarked pixels by assigning value "0", thus subtracting the background. Skin color detection and background subtraction results are shown in Fig. 4(a) and 4(b).



(a) (b)

Fig. 4: (a) Skin Color Detection (b) Hand Segmentation using background subtraction

D. Hand Geometric Features

After hand segmentation, geometric features of hand such as centroid and pose orientation are calculated. These geometric features will be used in subsequent stages.

Centroid depicts the central point of hand region and pose orientation tells the direction of the hand. Many properties of image can be calculated by using moment of the image [20]. These moments are calculated using regional properties of hand. For a 2D continuous function $f(x,y)$, moment is defined as

$$M_{pq} = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} x^p y^q f(x,y)\,dx\,dy \qquad (2)$$

The first order moment in x and y, normalized by the area, gives the centroid feature of hand region:

$$\bar{x} = \frac{M_{10}}{M_{00}}, \bar{y} = \frac{M_{01}}{M_{00}} \qquad (3)$$

$\bar{x}$ and $\bar{y}$ in eq. (3) returns the centroid of the hand region. Fig. 5 shows the centroid for the hand region in Fig. 4(b). Pose orientation is the angle between the x-axis and the major axis of the ellipse that has the same second-moment as the region. It can be processed by fitting an ellipse to the region by matching first- and second-order moments [20]. Principal Major and minor axis passes through centroid .Their direction is given by expression:

$$\frac{1}{2}\left(\frac{\mu_{02}-\mu_{20}}{\mu_{11}}\right) \pm \frac{1}{2\mu_{11}}\sqrt{\mu_{02}^{2} - 2\mu_{02}\mu_{20} + \mu_{20}^{2} + 4\mu_{11}^{2}} \qquad (4)$$

Where

$$\mu_{11} = M_{01} - \bar{x}M_{01}$$

$$\mu_{20} = M_{20} - \bar{x}M_{10}$$

$$\mu_{02} = M_{02} - \bar{y}M_{01}$$

The moments can be estimated as mentioned below using intensities.

$$M_{00} = \sum_x \sum_y I(x,y) \qquad (5)$$

$$M_{10} = \sum_x \sum_y xI(x,y) \qquad (6)$$

$$M_{01} = \sum_x \sum_y yI(x,y) \qquad (7)$$

Fig. 5: Hand Centroid and Orientation (90°)

E. Hand Finger Tips Detection

This sub-unit focused on finger tips detection that is essential for finger identification and joints localization. Algorithm proceeds as drawing of five vectors from hand wrist towards finger tips and terminating those vectors at boundary points and which results in detection of finger tips. To take points on wrists five vectors are drawn from hand centroid towards wrist using the formula depicted below in eqs. (8) and (9):

$$X(i,j) = Cx + (r * \cos\theta) \qquad (8)$$

$$Y(i,j) = Cy + (r * \sin\theta) \qquad (9)$$

Where 'Cx and Cy' are the x and y coordinates of hand centroid, 'r' is the radius and 'Θ' is the orientation. Initially radius of 400 was chosen as it is good approximation to cover hand of all lengths and orientation of 70 degree for first vector and 12° is added for each subsequent vector.

Contour tracing is applied to draw contour around segmented hand. Then intersection of the vectors with the boundary at the appropriate positions is observed. It is performed by comparing all boundary points with each vector and matching point is saved in an array which resulted in five wrist points. Results of detecting wrist points are shown in Fig. 6(a). Five vectors are drawn from those wrist points towards hand fingers and finger tips are detected in the same way as vectors intersect the farthest boundary points. Fig. 6(b) illustrates the vector drawing from wrist pints towards the fingertips.

Fig. 6: (a) Hand Wrist Points Detection (b) Finger Tips Detection

F. Joints Localization and Finger identification

This sub-unit proceeds as tagging of hand type (Left or Right), identification of fingers, and localization of finger joints. In order to identify hand type, length of all five vectors drawn in Fig. 6(b) is calculated using formula given below:

$$L = \sqrt{(y_2 - y_1)^2 + (x_2 - x_1)^2} \qquad (10)$$

These lengths are than normalized and stored for future use. Simple logical analysis decides the tagging of hand. If the length of first vector is greater than fifth then it is right hand else it is left hand under the assumption that all four fingers and thumb are present in image.

Tagging of hand let the finger identification process quite simplified. In case of right hand then first vector will be representing pinky finger, similarly second, third, fourth and fifth vector represent the ring, middle, index and thumb respectively. For left hand the assigning order of fingers would be reversed.

Hand dimensions vary largely among humans. However, the progression of each finger approximately follows the Fibonacci sequence as seen by the average interarticular lengths of the proximal phalanges (46 mm), middle phalanges (28 mm), and distal phalanges (18 mm). [21]. As per this approximation, five vectors representing four fingers and thumb are segmented with ratios given below to find out the approximate location of joints in each finger and thumb.

It was found out that for fingers, metacarpophalangeal (MCP) joint, proximal interphalangeal (PIP) joint and distal interphalangeal (DIP) joint was located approximately at 55%, 73% and 86 % of vector length and for Thumb interphalangeal (IP) joint and MCP was located at 45% and 70 % of vector length .This approximation may work for hands of varying lengths. All detected characteristics and features by criteria mentioned above are than mapped to original hand and thus completing 2D hand kinematic model as shown in Fig. 7. Green markers represent finger tips, red represents DIP, yellow represents PIP and blue represents MCP.

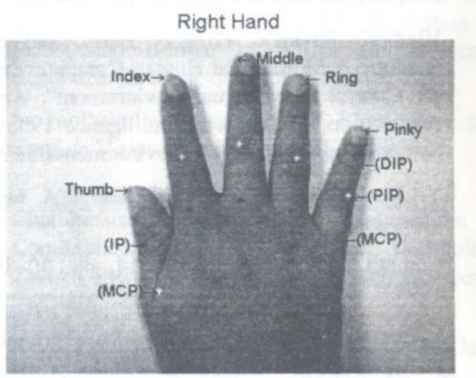


Fig .7: Kinematic Model of Hand Showing Identification of Fingers and Localization of Joints.

III. Experimental Results

Hand images with different poses were captured in daily-life conditions for the testing of the proposed algorithm. Fig. 8 shows the three poses for each hand i.e. (a) right hand pose at 90° (b) right hand pose at 60°(c) right hand pose at -60°(d) left hand pose at 90°(e) left hand pose at 60°(f) left hand pose at -60°.

Proposed algorithm of section II was applied to these images and result for color balancing, skin color detection, hand segmentation and centroid estimation, finger tip detection and finger identification and joints localization can be seen in Fig. 9, 10, 11, 12 and 13 respectively.

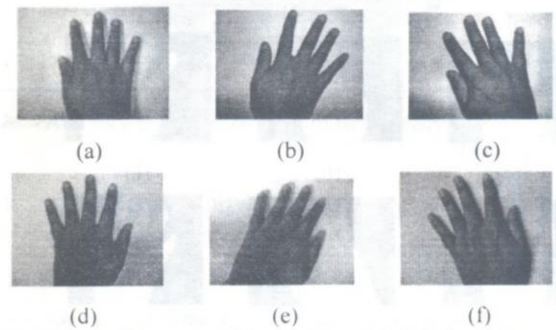


Fig. 8: Input images at different poses (a) right hand pose at 90° (b) right hand pose at 60°(c) right hand pose at -60°(d) left hand pose at 90°(e) left hand pose at 60°(f) left hand pose at -60°.

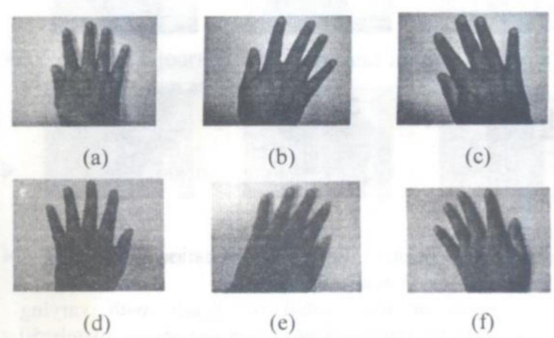


Fig. 9: Input hand Images after implying color balancing.

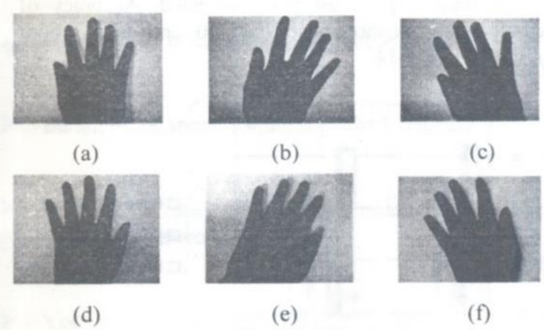


Fig. 10. Marked skin pixels

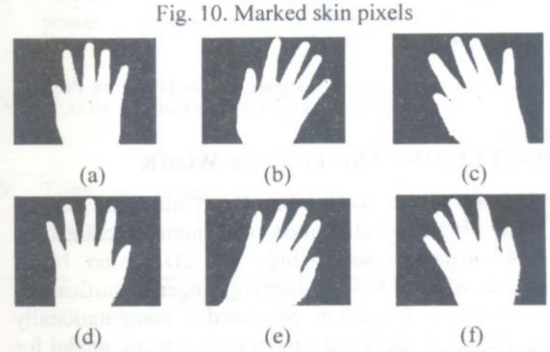


Fig. 11: Hand Segmentation with Centroid and Orientation

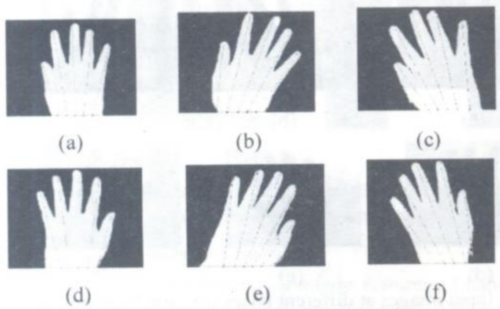


Fig. 12: Finger tips and Wrist points

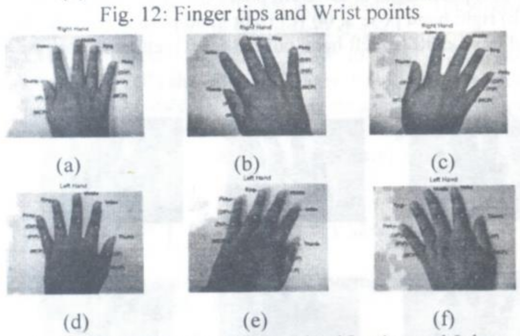


Fig 13: Hand Tagging, Finger Identification and Joints Localization Results

Proposed algorithm was tested on hands with varying dimensions. For this purpose hand images of approximately 50 different persons were acquired, tested and very acceptable results were produced for all poses of hand. Accuracy of proposed algorithm for three poses (60°, 90° and -60°) of both hands is shown in Fig 14.

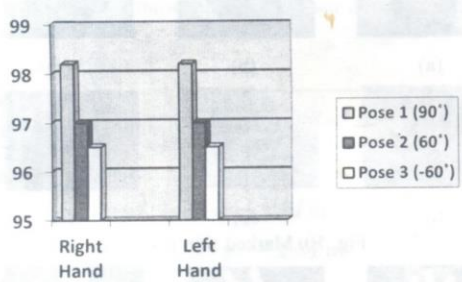


Fig.14. Accuracy of Proposed Algorithm for Different Poses

IV. CONCLUSIONS AND FUTURE WORK

Research work aimed to develop Hand kinematic model (HKM) for finger identification and joints localization, which was achieved successfully. A 2D vision based approach was adapted to hand tagging, finger identification, joints localization. Algorithm presented a computationally fast mechanism for the development of kinematic model for static hand poses. Reliable results were observed by apply algorithm on different hand poses of various persons.

In future, research work will be focused on developing kinematic model of hand under diverse backgrounds, cluttered environments and varying lightning conditions. Finger identification and joints localization can be employed in various hand recognition applications and can be taken into account in HCI application as well. Research work can be deployed in developing mechanism for non-contact mouse, controlling of home appliances, vision based virtual keyboard and in-car applications etc. Use of thermal images or bone scans of hands for structural analysis can lead to better medical diagnosis for the patients. Deployment of joint shape and motion information of hands may reveal new dimensions in human activity recognition.

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REFERENCES

[1] J.K.Aggarwal, Q.Cai, "Human Motion Analysis: A Review," IEEE proc. Nonrigid and Articulated Motion Workshop'97, pp90-102, 1997.

[2] R.Kjeldesn, J.Kender, "Toward the Use of Gesture in traditional User Interfaces", IEEE Automatic Face and Gesture Recognition, pp151-156,1996.

[3] Vladimir Pavlovic, Gregory Berry, and Thomas Huang, "A Multimodal Human-Computer Interface for Control of a Virtual Enviornment", American Association for Artificial Intelligence 1998 Spring Symposium on Intelligent Environments, 1998.

[4] Y. D. J. Sturman and D. Zeltzer, "A survey of glove-based input," IEEE

Comput. Graph. Appl., vol. 14, pp. 30–39, Jan. 1994.

[5] J. Lee and T. L. Kunii, "Model-based analysis of hand posture," IEEE

Comput. Graph. Appl., pp. 77–86, Sept. 1995.

[6] B. Moghaddam and A. Pentland, "Probabilistic visual learning for object recognition," IEEE Trans. Pattern Anal. Machine Intell., vol. 19, pp.696–710, July 1997.

[7] T. Staner, J. Weaver, and A. Pentland, "Real-time American sign language recognition using desk and wearable computer based video,"IEEE Trans. Pattern Anal. Machine Intell., vol. 20, pp. 1371–1375, Dec. 1998.

[8] Y. Cui and J. Weng, "A learning-based prediction-and-verification segmentation scheme for hand sign image sequence," IEEE Trans. Pattern Anal. Machine Intell., vol. 21, pp. 798–804, Aug. 1999.

[9] Taehyun Rhee ,Ulrich Neumann , J.P. Lewis "Human Hand Modeling from Surface Anatomy " ,ACM SIGGRAPH Symposium on Interactive 3D Graphics and Games,2006.

[10] Parida, P K Biswal, B B Khan, M R , “Kinematic Modeling and Analysis of a Multifingered Robotic Hand “,Advanced Materials Research Vols. 383-390 , pp 6684-6688 ,2012

[11] Ying Wu, Thomas S. Huang "Hand modeling, analysis and recognition ”, Signal Processing Magazine, IEEE , Volume: 18 , Issue: 3 ,Page(s): 51 – 60 ,2001.

[12] G.D. Finlayson, B. Shiele and J.L. Crowley. Comprehensive colour normalization Proc. European Conf. on Computer Vison (ECCV). Vol. I, 475-490, Freiburg, Germany. 1998

[13] Jose M. Buenaposada; Luis Baumela , “Variations of Grey World for face tracking” ,International Conference on Computer Analysis of Images and Patterns. Vol. 7, no 3-4, 2001 .

[14] M.Cote,P. Payeur, and G. Comeau. Comparative study of adaptive segmentation techniques for gesture analysis in unconstrained environments. In IEEE Int. Workshop on Imagining Systems and Techniques, pages 28 to 33, 2006.

[15] J. Fritsch, S. Lang, M. Kleinehagenbrock, G. A. Fink and G. Sagerer, IEEE Int. Workshop OIL Robot and Human Interactive Communication, September 2002.

[16] N. Tanibata, N. Shimada and Y. Shirai, Proc. oflnt. Conf on Virion Interface, pp.391-398.2002.

[17] N. Soontranon, S. Aramvith and T. H. Chalidabhongst, lntcmatiorial Symposium on Communications and Information Technologies 2M14 (ISCLT 2004) Sapporo, Japan, October 26-29, 2004.

[18] R. L. Hsu, M. Abdel-Mottaleh and A. K. Jain, , IEEE Tram. on Pattern Airalysir and Machine Intelligence,vo1.2, NOS, pp.696-706, May 2002.

[19] J. Yang and A. Waibel, Proc. of Third Workshop OII Applications of Computer Vision, 1996, pp.142-147.

[20] Haralick and Shapiro, Computer and Robot Vision vol. 1, Appendix A, Addison-Wesley ,1992.

[21] Johan M. F. Landsmeer Fadi J. Beijjani. “Basic Biomechanics of the Musculoskeletal System". In: ed. by M Nordin and VH Frankel. Lea & Febiger, Chap. Biomechanics of the hand, pp. 275 to 304, 1989.

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Quotations

- Adultery is the application of democracy to love.
  H.L. Menchen

- There’s nothing like a good dose of another woman to make a man appreciate his wife.
  Clare Boothe Luce

- No act of kindness, no matter how small, is ever wasted.
  Aesop

- All cruelty springs from weakness.
  Seneca the Younger

- Peace is a journey of a thousand miles and it must be taken one step at a time.
  Lyndon B. Johnson

- Nothing can bring you peace but yourself.
  Ralph Waldo Emerson

- Peace hath her victories, no less renown’d than war.
  John Milton

- Peace, like charity begins at home..
  Franklin D. Roosevelt

- Superstition is the religion of feeble minds.
  Edmund Burke

- Be silent, or speak something worth hearing.
  Thomas Fuller

- Nothing so stirs a man’s conscience or excites his curiosity as a woman’s silence.
  Thomas Hardy

- You can never give complete authority and overall power to anyone until trust can be proven.
  Bill Cosby

- You never find yourself until you face the truth.
  Pearl Bailey

- Truth, like surgery, may hurt, but it cures.
  Han Suyin