Global Journal of Computer Science and Technology: F
Graphics & vision
Volume 16 Issue 2 Version 1.0 Year 2016
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 0975-4172 & Print ISSN: 0975-4350

Towards Developing an Effective Hand Gesture Recognition System for Human Computer Interaction: A Literature Survey

By Santosh Choudhary & Dr. Naveen Choudhary
College of Technology and Engineering

Abstract- Gesture recognition is a mathematical analysis of movement of body parts (hand / face) done with the help of computing device. It helps computers to understand human body language and build a more powerful link between humans and machines. Many research works are developed in the field of hand gesture recognition. Each works have achieved different recognition accuracies with different hand gesture datasets, however most of the firms are having insufficient insight to develop necessary achievements to meet their development in real time datasets. Under such circumstances, it is very essential to have a complete knowledge of recognition methods of hand gesture recognition, its strength and weakness and the development criteria as well. Lots of reports declare its work to be better but a complete relative analysis is lacking in these works.

Keywords: hand gesture recognition, neural network (NN), hidden markov model (HMM), Support Vector Machine (SVM), Principle Component Analysis (PCA).

GJCST-F Classification : I.4.8, I.7.5, I.5.1, J.5

Strictly as per the compliance and regulations of:

Towards Developing an Effective Hand Gesture Recognition System for Human Computer Interaction: A Literature Survey

Santosh Choudhary [α] & Dr. Naveen Choudhary [σ]

Abstract- Gesture recognition is a mathematical analysis of movement of body parts (hand / face) done with the help of computing device. It helps computers to understand human body language and build a more powerful link between humans and machines. Many research works are developed in the field of hand gesture recognition. Each works have achieved different recognition accuracies with different hand gesture datasets, however most of the firms are having insufficient insight to develop necessary achievements to meet their development in real time datasets. Under such circumstances, it is very essential to have a complete knowledge of recognition methods of hand gesture recognition, its strength and weakness and the development criteria as well. Lots of reports declare its work to be better but a complete relative analysis is lacking in these works.

In this paper, we provide a study of representative techniques for hand gesture recognition, recognition methods and also presented a brief introduction about hand gesture recognition. The main objective of this work is to highlight the position of various recognition techniques which can indirectly help in developing new techniques for solving the issues in the hand gesture recognition systems. Moreover we present a concise description about the hand gesture recognition systems recognition methods and the instructions for future research.

Keywords: hand gesture recognition, neural network (NN), hidden markov model (HMM), support vector machine (SVM), principle component analysis (PCA) .

I. Introduction

Human computer interaction (HCI) refers to the association between the human and the computer. The machine has no importance if it is not properly exploited. That is also called Man-Machine-Interaction (MMI).For the designing of HCI system we speculate on two important concepts: usability and functionality[9]. The system can be robust and affective on securing balance between usability and functionality. Gestures are to make an efficient and effective way on interaction and communication between the people adopting sign language[1] [10].Usually, HCI is consummate with devices such as mouse and keyboard, which are restricted in terms of operational distance and convenience. By contrast, hand gesture recognition provides an alternative to these awkward devices, and enables people to communicate with computer more easily and naturally [2].

Gestures recognition system increasingly becomes a significant part of human-computer interaction. Movement of humans creates the gestures. Face and/or hands are the sources of gestures. The movement of the body reflects the information/feeling through gestures. Gesture can be “saying hello” but typing something on keyboard is not considered gesture. It is because the movement of fingers typing on the keyboard is not noticeable.

Gestures are of two types: Static and Dynamic. The shape of poses of hands depicts Static Gesture whereas their movement is Dynamic Gesture [7]. Gestures have different versions based on culture/ region of different people which creates diversity and uncertainty [8].

Hand gesture is defined as the combination of all kinds of gestures and movements which produced by hand and arm[8]. Hand gesture is the most animated, mobile, communicative and the most often used, among a range of gestures. Gestures have been utilized as a form to communicate or interact with computers in an effortless and simple way. This type of human-machine interfaces will permit a user to manage and control an ample range of devices through hand gestures recognition. Using hands as a tool can support people interact with PC in a much intuitive way. When they communicate with other people their movements of hand plays an essential role and the data they convey is rich in several ways. They use their hands for denoting an object or person conveying data about shape, temporal and space features. They steadily use their hands to communicate with objects, change them, transform them and move them. In similar unconscious way they gesticulate while interacting to notions. Hand gesture recognition can be mainly divided into two types such as Data Glove-based and Vision based approaches [3]. Data Glove-based approach use a data glove to acquire a motion. In this approach it is possible to analyze 3D space hand motion with perceived data. As it is tedious and incurs high cost, it is not convenient for the user. The users have limitations in using the Vision based methods. Vision based methods have come up as a research area for improving Human

Author α : College of Technology and Engineering, MPUAT,Udaipur.
e-mail: santoshchoudharycs@gmail.com

Computer interaction without use of keyboard, mouse etc. [3].

Vision-based hand gesture recognition has pinched considerable attention from researchers in recent years. An automatic hand gesture recognition system will discover many applications in Human-Computer Interaction area. Hand gesture detection is a fundamental step in the practical application process of this system. It requires the ability to accurately segment the hand from the background. Due to the difficulty of this task, early systems usually require markers or colored gloves to make the detection easier. However, these methods often bring much in convenience for the Human-Computer Interaction process. Moreover, the current research is mainly focused on detecting the bare hand and recognizing hand gestures without any markers and gloves [5].

These days gesture recognition technique is used in a broad range like in Virtual reality, video games, sign language recognition etc. Gesture recognition is done by tools based on various methods like statistical modeling, signal and image processing, pattern recognition and computer vision etc. Statistical modeling been one of the most widely used methods in resolving problems such as HMMs, Kalman filtering, PCA and Finite State Machine (FSM) [6][12][13].

II. Review of Recent Researches on Hand Gesture Recognition System

Hand gesture recognition methods use different research approaches and these approaches are grouped together based on their techniques which they are using in the process of hand gesture recognition. By exploiting different recognition methods, the hand gesture recognition process is examined. Different types of recognition methods utilized by the researchers are such as HMM, NN and SVM, these methods plays vital role in hand recognition method. Most of the earlier researches were based on HMMs, NN and SVM.

a) Literature survey on HMM Based Recognition Methods in Hand Gesture Recognition System

Model based hand recognition system which consists of three phases; feature extraction, training and recognition. In feature extraction phase, spatial and temporal information of each frame is combined by the hybrid technique to extract the feature images. In training phase, spatial shape variation is characterized by principal component analysis (PCA) and temporal shape variations are described through Hidden Markov Models (HMMs). Generation of observation patterns from the input sequences is done with pre-trained PCA and HMMs in the recognition phase. After this Viterbi algorithm is applied for gesture identification [14].

HMM has been proposed for various types of hand gesture recognition. Hand localization, hand tracking and gesture spotting are the three different procedures in the pre-processing stage of this approach. In hand location detection procedure, hand region is detected on the basis of motion and color of skin. A hand trajectory is produced by joining the centroids of moving hand region. The centroid of the moving hand regions is detected through hand tracking algorithm. There after the gesture spotting algorithm separates the trajectory into real and meaningless sectors. A feature database is constructed using angle and velocity feature codes, combined and weighted location uses a k-means clustering algorithm for Hidden Markov Models code book.

Similarly different authors in their papers [16][17][18][19] and [20] have proposed different models or methods or techniques for a hand gesture recognition system.

But hand gesture recognition system is described in "Wearable Sensor-Based Hand Gesture and Daily Activity Recognition for Robot-Assisted Living", here gesture spotting is done by neural network and for contact-based recognition it used hierarchical HMM. The motion data collected from foot and waist of a human subject is processed by a multi-sensor fusion developed for daily activity recognition.

Use of two sensors, three axis accelerometer (ACC) and multichannel electromyography (EMG) sensors, is done for hand gesture recognition [22]. The intensity of EMG signals automatically detects the start and end points of significant gesture segments. The final result is obtained by utilizing a decision tree and multi-stream HMMs as decision level fusion.

b) Literature survey on NN Based Recognition Methods in Hand Gesture Recognition System

Based on motion trajectories, an algorithm classifies and extracts of two-dimensional motion in an image sequence. A homogenous region is generated in each frame by multi-scale segmentation. Two view correspondences are obtained by matching region between two consecutive frames. In order to define pixel match, a fine transformation is calculated from each pair of the corresponding regions.

Pixel-level motion trajectories are obtained by concatenating the pixel matches over consecutive images across the image sequence. Time delay neural network is used to learn about the motion patterns from the extracted trajectories. Forty hand gestures of American Sign Language are recognized in the proposed method.

Similarly different authors in their papers [24][25][26][27][28][29][30] and [31] have proposed different models or methods or techniques or ideas for a hand gesture recognition system.

A method of Hand gesture recognition in Indian Sign Language is proposed [32]. In this the Histograms of Oriented Gradients (HOG) features are used for

recognizing alphabets (A-Z) and numerals (0-9) with a purpose to implement the algorithm of extracting HOG features. The Histograms of Oriented Gradients (HOG) features are used for passing in neural network training for the gesture recognition purpose.

Using neural network a vision based sign gesture recognition system is proposed [33]. In the first step the images of static gestures of American Sign Language were converted into Lab Color space by the system. Parameter L denotes lightness & (a,b) are the dimensions of color-opponent. With color-opponent dimensions skin region segmentation is done using threshold technique. For feature extraction, hand (skin region) is cropped and converted into binary image. After this other dimensions (like height, area, centroid, centroid-distance from the origin) of the image are used as features. In order to train a feed forward back propagation network, we use feature vectors of each set.

c) Literature survey on SVM Based Recognition Methods in Hand Gesture Recognition System

Daehwankim et al have proposed a forward spotting scheme with sliding window and accumulative HMMs. Recognition and segmentation of gesture is executed simultaneously and it is applied to identify upper body gestures for controlling the lights and curtains in a smart home environment [34].

A user independent framework is proposed for demonstrating and identifying hand postures that are used in sign language [35].A hand posture feature, an Eigen space Size Function are proposed, which is robust to classify hand postures independent of the performer. On analysis of the properties of the proposed Eigen space size function, a significant improvement in performance is seen w.r.t original unmodified size function.

In [36] they have used twin support vector machine for gesture classification based on EMG, and shows that this technique is extremely suited to such applications.

Similarly different authors in their papers [37][38][39][40] have proposed different models or methods or ideas for a hand gesture recognition system.

A Gesture Recognition system for Alphabetical Hand Gestures was proposed to simplify the process of interaction of humans with computer [41]. Design of the system is done with the use of Support Vector Machine (SVM) classifier. SVM classifiers are widely used in classification and regression testing. A model is built by SVM training algorithm which predicts if a new example falls into one category or the other.

d) Literature survey on other Methods in Hand Gesture Recognition System

An approach based on fuzzy rule to spatio-temporal hand gesture recognition system is proposed in [42]. For selecting templates, it uses a method based on hyper rectangular composite neural networks (HRCNNs). If-THEN rules, represents the templates for each hand shape, If-THEN rules are obtained from values of synaptic weights of the corresponding trained hyper rectangular composite neural networks (HRCNNs) A special membership function is employed to fuzzify each crisp IF-THEN so that the pattern has similarity to the corresponding predecessor part. For the classification of any unknown gesture, each fuzzy rule tests each sample of the unknown gesture. The collected similarity of all the input samples is computed for each hand gesture in the vocabulary, and then the gesture can be classified as gesture yielding the highest accumulative similarity. A small sized dynamic hand gesture can be implemented based on the method used.

Similarly different authors in their papers [43][44][45][46][47][48][49][50][51][52][53] and [54] have proposed different models or methods or ideas for a hand gesture recognition system.

For gesture recognition, an algorithm framework was proposed which processed acceleration and surface electromyography (SEMG) signals [55].This algorithm includes a score-based sensor fusion scheme, a segmentation scheme and two new features. An improved dynamic time-warping algorithm and bays linear classifier are used in the framework. In addition to that a prototype system is developed to realize gesture-based real-time interaction. The prototype system includes an application program with the proposed algorithmic framework for a mobile phone and a wearable gesture sensing device (embedded with a three-axis accelerometer and four SEMG sensors).

Along with Kinect depth camera a super pixel hand gesture recognition technique based on a novel super pixel earth mover's distance metric was presented [56]. Marker less hand extraction is produced by effectively utilizing the depth and skeleton information from Kinect. The super pixels were represented by the hand shapes, corresponding depths and textures. Overall shapes and color of the gestures, to be recognized, is effectively retained. The dissimilarity between the hand gestures is proposed to be measured by super pixel Earth mover's distance (SP-EMD) and a novel distance metric.

III. Performance Review of Hand Gesture Recognition System

Hand gesture recognition systems have attained different recognition accuracy by using different recognition methods with different database. Here we have to analysis the hand gesture recognition methods recognition accuracy by differentiate the recognition methods. The different recognition methods recognition accuracies are tabulated from Table 1 to 4.

Table 1 : Performance of HMM based hand gesture recognition methods

Author's Name	Database	Recognition Accuracy (%)
Chung-Lin Huang and Sheng-Hung Jeng [14]	18 different gestures from 20 people	Simple gesture 92% Hybrid gesture 87%
Ho-Sub Yoon *et al.* [15]	4800 alphabetical gestures of 20 persons	Cartesian system 96.10% polar systems 96.04%
Feng-Sheng Chen *et al.* [16]	20 different gestures	>90%
Agnes Just *et al.* [20]	Interact Play database Two Hand Manip database	75% and 63% 99% and 97%
Chun Zhu *et al.* [21]	Five gesture data	82% and 91%
Xu Zhang *et al.*[22]	8640 CSL word samples 800 sentence samples	93.1% 72.5%

As mention in the above table-1 in performance of HMM based hand gesture recognition methods, we first analyze the HMM based hand gesture recognition methods with following data. Chung-Lin Huang and Sheng-Hung Jeng have taken simple gestures and hybrid gestures as input data. They have performed test on 10 simple gesture and 8 hybrid gestures and found correct recognition rate for simple gesture above 92% and the hybrid gesture is about 87%.

Similarly different authors analyze with different input data and got different outputs which are given in the above table.

Table 2 : Performance of NN based hand gesture recognition methods

Author's Name	Database	Recognition Accuracy (%)
Ming-Hsuan Yang *et al.* [23]	40 hand gestures	96.21%
Chia-Feng Juang*et al.* [24]	100 temporal gestures	92%
S.S. Ge*et al.* [25]	280 gesture samples	91.9%
Stergiopoulou*et al.* [26]	180 test hand images	90.45%
Heung-Il Suk *et al.* [27]	10 isolated gestures	99.59%
JawadNagi*et al.* [28]	2400 gesture images	96%
Wensheng Li *et al.*[29]	200 samples	94.7%
Trong-Nguyen Nguyen *et al.* [30]	445 samples	98%
Ao Tang *et al.* [31]	36 hand postures	98.12%
Parul Chaudhary *et al.* [33]	-	85%

As mention in above table-2 in performance of NN based hand gesture recognition methods we analyze second NN based hand gesture recognition methods with following data. Ming-Hsuan Yang et al. have applied the proposed method to recognize 40 hand gestures of American Sign Language. The resulting average recognition rates on the training and testing sets for gesture recognition were 99.02% and96.21%, respectively. Similarly different authors analyze with different input data and got different outputs which are given in the above table. Parul Chaudhary *et al.* trained and tested images with the help of image dataset of the proposed system. The dataset of images contains '.jpg format' of four static sign gestures of ASL. The performance of the proposed system was analyzed by the created image database that achieved an average recognition accuracy of 85%.

Table 3 : Performance of SVM based hand gesture recognition methods

Author's Name	Database	Recognition Accuracy (%)
Daehwan Kim *et al.* [34]	480 test gesture sequences	95.42%
Daniel Kelly *et al.* [35]	ISL Triesch	97.3% 93%
Ganesh R. Naik *et al.* [36]	49 sets of data	86%
Nasser H. Dardas *et al.* [38]	Sebastien Marcel database	96.23%
Daniel Kelly *et al.* [39]	962 signs	82.3%
Nasser H. Dardas *et al.* [40]	Four gestures with 1000 frames	97.6%
Aseema Sultana *et al.* [41]	5 alphabetical dynamic hand gestures	80%

As mention in above table-3 in performance of SVM based hand gesture recognition methods we analyze third SVM based hand gesture recognition methods with following data. Daehwan Kim *et al.* have used 480 test gesture sequences and results show that the proposed method has a good recognition rate of 95.42% for continuously changing gestures.

Daniel Kelly *et al.* have taken two different datasets: ISL and Triesch. 5520 hand postures images were used to train the SVMs, for the ISL data set. Data of half of the 16 subjects constituted the 5520 training images. On the remaining 5520 images, the recognition framework was tested. Two evaluation protocols (P1 & P2) were carried out for the Triesch data set.

Based on the same protocol as Triesch and von der Malsburg, the first evaluation was performed (2002). The data extracted from 3 of the 24 signer was used in the training of the SVMs on each of the 10 hand signs. Testing of the system is done on all the hand signs from remaining 21 subjects. In second evaluation, 8 of the 24 signers are used for training a validation and for testing the rest of the 16 used. The result of the experiments shows that the system is robust and recognition of hand gestures is independent of the person performing them. Similarly different authors analyze with different input data and got different outputs which are given in the above table.

Table 4 : Performance of other methods in hand gesture recognition

Author's Name	Database	Recognition Accuracy (%)
Mu-Chun Su [42]	90 spatio-temporal hand gestures	94.1% and 91.2%
Juan P. Wachs *et al.* [43]	Gripsee	93.75%
George Caridakis*et al.* [45]	30 gestures	93%
Deng-Yuan Huang *et al.* [46]	-	96.1%
Ruize Xu *et al.* [47]	628 gestures	95.6%
Luigi Lamberti *et al.* [48]	907 hand gestures	98.46%
Zhou Ren *et al.* [50]	-	93.2%
Yuan Yao *et al.* [51]	SQLite database	51.87%
Kui Liu *et al.*[53]	Microsoft MSR dataset	93%
Eshed Ohn-Bar *et al.* [54]	19 hand gestures	98.4%, 99.7% and 92.8%
Zhiyuan Lu *et al.* [55]	19 predefined gestures	95.0% and 89.6%
Chong Wang *et al.* [56]	Own dataset NTU hand digit dataset ASL finger spelling dataset	97.2% and 99.1% 99.6% 75.8%

As mention in above table-4 in performance of other methods in hand gesture recognition we analyze other methods in hand gesture recognition with following data. Mu-Chun Su used two data bases, for verifying its performance, comprised of 90 spatio-temporal hand gestures.. In first and second database he achieved 94.1% and 91.2% recognition results.

But Juan P. Wach s *et al.* have taken three types of gesture dataset (Gripsee, BGU and American Sign Language) and using the real-time implementation (Tele- Gest) compared the performance. In the comparison of user-dependent and user-independent systems 13 gestures dataset was made. Accuracies of 98.9% and 98.2% of the system were found for user-dependent and independent systems respectively on testing with their own trainer. The Gripsee system achieved 93.75% of recognition accuracy.

On an artificial dataset formed by 30 gestures, validation of the proposed architecture was performed by George Caridaki *set al*. 10-fold cross validation strategy was used in this experiment. An average recognition rate of 93 % was achieved.

Similarly different authors analyze with different input data and got different outputs which are given in the above table.

IV. Direction for The Future Research

In our review work, hand gesture recognition system is analyzed by using different recognition techniques. Here all the proposed methods are worked efficiently but these methods give high performance on the particular datasets. The datasets contains background images and face images datasets have the small recognition accuracy value than the other datasets. Hence there is a need to develop new techniques in the datasets with background and face images. So the proper analysis is to be needed. As a result this review paper will be supportive for the researchers to improve the hand gesture recognition system in real time datasets. We believe that in future various works will arise using our review work.

V. Conclusion

In this paper, an extensive survey has been performed about different recognition techniques used in the system of hand gesture recognition. While all the methods proposed are fairly accurate. Our goal of hand gesture recognition process needs to further perfect those approaches or develop some more efficient methods. Here the researches are categorized based on recognition techniques that are exploited in hand gesture recognition process and also an introduction about hand gesture recognition is presented. From this review, the researchers can able to know about several recognition techniques and their performance existing in hand gesture recognition system.

References Références Referencias

1. Rafiqul Zaman Khan and Noor Adnan Ibraheem, "Hand Gesture Recognition: A Literature Review', International Journal of Artificial Intelligence & Applications (IJAIA), Vol. 3, No. 4, pp. 161-174, 2012.
2. Yanmin Zhu, Zhibo Yang, Bo Yuan, "Vision Based Hand Gesture Recognition", International Conference on Service Science, pp. 260-265, 2013.
3. Huaiyu Xu, Xiaoyu Hou, Ruidan Su and Qing Ni, "Real-Time Hand Gesture Recognition System Based on Associative Processors", IEEE International Conference on Computer Science and Information Technology, Beijing, pp. 14-18, 2009.
4. Dharani Mazumdar, Anjan Kumar Talukdar and Kandarpa Kumar Sarma, "A Colored Finger Tip-Based Tracking Method For Continuous Hand Gesture Recognition", International Journal of Electronics Signals and Systems (IJESS),Vol. 3, No. 1, pp. 71-75, 2013.
5. Liu Yun and Zhang Peng, "An Automatic Hand Gesture Recognition System Based on Viola-Jones Method and SVMs", Second International Workshop on Computer Science and Engineering, Qingdao, Vol. 2, pp. 72-76, 2009.
6. Zhong Yang, Yi Li, Weidong Chen and Yang Zheng, "Dynamic Hand Gesture Recognition Using Hidden Markov Models", The 7th International Conference on Computer Science & Education, Melbourne, Australia, pp. 360-365, 2012.
7. Dipak Kumar Ghosh and Samit Ari, "A Static Hand Gesture Recognition Algorithm Using K-Mean Based Radial Basis Function Neural Network", International Conference on Information, Communications and Signal Processing, Singapore, pp. 1-5, 2011.
8. Lingchen Chen, Feng Wang, Hui Deng and Kaifan Ji, "A Survey on Hand Gesture Recognition", International Conference on Computer Sciences and Applications, Wuhan, pp. 313-316, 2013.
9. Kamal K Vyas, Amita Pareek and Tiwari, Gesture Recognition and Control Part 2–Hand Gesture Recognition (HGR) System & Latest Upcoming Techniques, International Journal on Recent and Innovation Trends in Computing and Communication, Vol. 1, No. 8, pp. 632-637, 2013.
10. Deepali N. Kakade and Chitode, Dynamic Hand Gesture Recognition: A Literature Review, International Journal of Engineering Research & Technology (IJERT), Vol. 1, No. 9, pp. 1-7, 2012.
11. Xu Yan and Nuerrennisahan Aimaiti, Gesture-based interaction and implication for the future, Master Thesis, Department of Computing Science, Umea University, Sweden, 2011.
12. Priya Gairola and Sanjay Kumar, Hand Gesture Recognition From Video, International Journal of Science and Research (IJSR), Vol. 3, No. 4, pp. 154-158, 2014.
13. Vishal Nayakwadi and Pokale, Natural Hand Gestures Recognition System for Intelligent HCI: A Survey, International Journal of Computer Applications Technology and Research, Vol. 3, No. 1, pp. 10-19, 2013.
14. Chung-Lin Huang and Sheng-Hung Jeng, "A model-based hand gesture recognition system", Machine Vision and Applications, Vol. 12, pp. 243–258, 2001.
15. Ho-Sub Yoon, Jung Soh, Younglae J. Bae and Hyun Seung Yang, "Hand gesture recognition using combined features of location, angle and velocity", Pattern Recognition, vol. 34, pp. 1491-1501, 2001

16. Feng-Sheng Chen, Chih-Ming Fu and Chung-Lin Huang, "Hand gesture recognition using a real-time tracking method and hidden Markov models", Image and Vision Computing, Vol. 21, pp. 745–758, 2003.
17. MA Gengyu and LIN Xueyin, "Operational Gesture Segmentation and Recognition", Tsinghua Science and Technology, Vol. 8, No. 2, pp. 163-173, 2003.
18. Aditya Rama moorthy, Namrata Vaswani, Santanu Chaudhury and Subhashis Banerjee, "Recognition of dynamic hand gestures", Pattern Recognition, Vol. 36, pp. 2069 – 2081, 2003.
19. Minh Anh T. Ho, Yoji Yamada, and Yoji Umetani, "An Adaptive Visual Attentive Tracker for Human Communicational Behaviors Using HMM-Based TD Learning With New State Distinction Capability", IEEE Transactions on Robotics, Vol. 21, No. 3, pp. 497-504, 2005.
20. Agnes Just and Sebastien Marcel, "A comparative study of two state-of-the-art sequence processing techniques for hand gesture recognition", Computer Vision and Image Understanding, vol. 113, pp. 532–543, 2009.
21. Chun Zhu and Weihua Sheng, "Wearable Sensor-Based Hand Gesture and Daily Activity Recognition for Robot-Assisted Living", IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans, Vol. 41, No. 3, pp. 569-573, 2011.
22. Xu Zhang, Xiang Chen, Yun Li, Vuokko Lantz, Kongqiao Wang and Jihai Yang, "A Framework for Hand Gesture Recognition Based on Accelerometer and EMG Sensors", IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems And Humans, Vol. 41, No. 6, pp. 1064-1076, 2011.
23. Ming-Hsuan Yang, Narendra Ahuja and Mark Tabb, "Extraction of 2D Motion Trajectories and Its Application to Hand Gesture Recognition", IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 24, No. 8, pp. 1061-1074, 2002.
24. Chia-Feng Juang and Ksuan-Chun Ku, "A Recurrent Fuzzy Network for Fuzzy Temporal Sequence Processing and Gesture Recognition", IEEE Transactions on Systems, Man, and Cybernetics—Part B: Cybernetics, Vol. 35, No. 4, pp. 646-658, 2005.
25. S.S. Ge, Y. Yang and T.H. Lee, "Hand gesture recognition and tracking based on distributed locally linear embedding", Image and Vision Computing, Vol. 26, pp. 1607–1620, 2008.
26. Stergiopoulou and Papamarkos, "Hand gesture recognition using a neural network shape fitting technique", Engineering Applications of Artificial Intelligence, Vol. 22, pp. 1141–1158, 2009.
27. Heung-Il Suk, Bong-KeeSin and Seong-WhanLee, "Hand gesture recognition based on dynamic Bayesian network framework", Pattern Recognition, Vol. 43, pp. 3059–3072, 2010.
28. Jawad Nagi, Frederick Ducatelle, Gianni A. Di Caro, Dan Ciresan, Ueli Meier, Alessandro Giusti, Farrukh Nagi, Jurgen Schmidhuber and Luca Maria Gambardella, "Max-Pooling Convolutional Neural Networks for Vision-based Hand Gesture Recognition", IEEE International Conference on Signal and Image Processing Applications, pp. 342-347, 2011.
29. Wensheng Li and Chunjian Deng, "Fast and Robust Method for Dynamic Gesture Recognition Using Hermite Neural Network", Journal of Computers, Vol. 7, No. 5, pp. 1163-1168, 2012.
30. Trong-Nguyen Nguyen, Huu-Hung Huynh and Jean Meunier, "Static Hand Gesture Recognition Using Artificial Neural Network", Journal of Image and Graphics, Vol. 1, No. 1, pp. 34-38, 2013.
31. Ao Tang, Ke Lu, Yufei Wang, Jie Huang and Houqiang Li, "A Real-time Hand Posture Recognition System Using Deep Neural Networks", ACM Transactions on Intelligent Systems and Technology, Vol. 9, No. 4, pp. 1-23, 2013.
32. Neha V. Tavari and Deorankar, "Indian Sign Language Recognition based on Histograms of Oriented Gradient", International Journal of Computer Science and Information Technologies, Vol. 5, No. 3, pp. 3657-3660, 2014.
33. Parul Chaudhary and Hardeep Singh Ryait, "Neural Network Based Static Sign Gesture Recognition System", International Journal of Innovative Research in Computer and Communication Engineering, Vol. 2, No. 2, pp. 3066-3072, 2014.
34. Daehwan Kim, Jinyoung Song and Daijin Kim, "Simultaneous gesture segmentation and recognition based on forward spotting accumulative. HMMs", Pattern Recognition, Vol. 40, pp. 3012 – 3026, 2007.
35. Daniel Kelly, John McDonald and Charles Markham, "A person independent system for recognition of hand postures used in sign language", Pattern Recognition Letters, Vol. 31, pp. 1359–1368, 2010.
36. Ganesh R. Naik, Dinesh Kant Kumar, and Jayadeva, "Twin SVM for Gesture Classification Using the Surface Electromyogram", IEEE Transactions on Information Technology in Biomedicine, Vol. 14, No. 2, pp. 301-308, 2010.
37. Shinko Y. Cheng and Mohan M. Trivedi, "Vision-Based Infotainment User Determination by Hand Recognition for Driver Assistance", IEEE Transactions on Intelligent Transportation Systems, Vol. 11, No. 3, pp. 759-764, 2010.
38. Nasser H. Dardas and Nicolas D. Georganas, "Real-Time Hand Gesture Detection and Recognition Using Bag-of-Features and Support Vector Machine Techniques", IEEE Transactions on Instrumentation and Measurement, Vol. 60, No. 11, pp. 3592 -3607, 2011.

39. Daniel Kelly, John Mc Donald and Charles Markham, "Weakly Supervised Training of a Sign Language Recognition System Using Multiple Instance Learning Density Matrices", IEEE Transactions on Systems, Man, and Cybernetics—Part B: Cybernetics, Vol. 41, No. 2, pp. 526-541, 2011.
40. Nasser H. Dardas and Mohammad Alhaj, "Hand Gesture Interaction with a 3D Virtual Environment", The Research Bulletin of Jordan ACM, Vol. 2, pp. 86-94, 2011.
41. Aseema Sultana and Raja puspha, "Vision Based Gesture Recognition for Alphabetical Hand Gestures Using the SVM Classifier", International Journal of Computer Science & Engineering Technology, Vol. 3 No. 7, pp. 218-223, 2012.
42. Mu-Chun Su, "A Fuzzy Rule-Based Approach to Spatio-Temporal Hand Gesture Recognition", IEEE Transactions on Systems, Man, and Cybernetics—Part C: Applications and Reviews, Vol. 30, No. 2, pp. 276-281, 2000.
43. Juan P. Wachs, Helman Stern and Yael Edan, "Cluster Labeling and Parameter Estimation for the Automated Setup of a Hand-Gesture Recognition System", IEEE Transactions on Systems, Man, and Cybernetics—Part A: Systems and Humans, Vol. 35, No. 6, pp. 932-944, 2005.
44. Qing Chen, Nicolas D. Georganas and Emil M. Petriu, "Hand Gesture Recognition Using Haar-Like Features and a Stochastic Context-Free Grammar", IEEE Transactions on Instrumentation and Measurement, Vol. 57, No. 8, pp. 1562-1571, 2008.
45. George Caridakis, Kostas Karpouzis, Athanasios Drosopoulos and Stefanos Kollias, "SOMM: Self organizing Markov map for gesture recognition", Pattern Recognition Letters, Vol. 31, pp. 52–59, 2010.
46. Deng-Yuan Huang, Wu-Chih Hub and Sung-Hsiang Chang, "Gabor filter-based hand-pose angle estimation for hand gesture recognition under varying illumination", Expert Systems with Applications, Vol. 38, pp. 6031–6042, 2011.
47. RuizeXu, Shengli Zhou and Wen J. Li, "MEMS Accelerometer Based Nonspecific-User Hand Gesture Recognition", IEEE Sensors Journal, Vol. 12, No. 5, pp. 1166-1173, 2012.
48. Luigi Lamberti and Francesco Camastra, "Handy: A real-time three color glove-based ge-0psture recognizer with learning vector quantization", Expert Systems with Applications, Vol. 39, pp. 10489–10494, 2012.
49. Shikha Guptaa, Jafreezal Jaafar and Wan Fatimah Wan Ahmad, "Static Hand Gesture Recognition Using Local Gabor Filter", International Symposium on Robotics and Intelligent Sensors, Procedia Engineering, Vol. 41, pp. 827-832, 2012.
50. Zhou Ren, Junsong Yuan, Jingjing Meng and Zhengyou Zhang, "Robust Part-Based Hand Gesture Recognition Using Kinect Sensor", IEEE Transactions on Multimedia, Vol. 15, No. 5, pp. 1110-1120, 2013.
51. Yuan Yao and Yun Fu, "Contour Model-Based Hand-Gesture Recognition Using the Kinect Sensor", IEEE Transactions on Circuits and Systems for Video Technology, Vol. 24, No. 11, pp. 1935-1944, 2014.
52. Shiguo Lian, Wei Hu and Kai Wang, "Automatic User State Recognition for Hand Gesture Based Low-Cost Television Control System", IEEE Transactions on Consumer Electronics, Vol. 60, No. 1, pp. 107-115, 2014.
53. Kui Liu, Chen Chen, Roozbeh Jafari and Nasser Kehtarnavaz, "Fusion of Inertial and Depth Sensor Data for Robust Hand Gesture Recognition", IEEE Sensors Journal, Vol. 14, No. 6, pp. 1898-1903, 2014.
54. Eshed Ohn- Barand Mohan Manubhai Trivedi, "Hand Gesture Recognition in Real Time for Automotive Interfaces: A Multimodal Vision-Based Approach and Evaluations", IEEE Transactions on Intelligent Transportation Systems, Vol. 15, No. 6, pp. 2368-2377, 2014.
55. Zhiyuan Lu, Xiang Chen, Qiang Li, Xu Zhang and Ping Zhou, "A Hand Gesture Recognition Framework and Wearable Gesture-Based Interaction Prototype for Mobile Devices", IEEE Transactions On Human-Machine Systems, Vol. 44, No. 2, pp. 293-299, 2014.
56. Chong Wang, Zhong Liu and Shing-Chow Chan, "Superpixel-Based Hand Gesture Recognition with Kinect Depth Camera", IEEE Transactions on Multimedia, Vol. 17, No. 1, pp. 29-39, 2015.