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Digital Pen for Handwritten Digit and Gesture Recognition Using Trajectory Recognition Algorithm Based On Triaxial Accelerometer

Leena Mahajan[1], Prof G. A. Kulkarni[2]
[1,2]*(Department of ECE,SSGB College of engineering and technology , Bhusawal, India)*

Abstract: *With the advent of computing technologies, specifically in the areas of improved computational speed and reduced system cost with additional functionalities, real-time and virtual interactions between humans and computers have gained significant research and commercial interests recently. So it is essential to focuses on human interactions with computing devices using characters and gesture recognition.*
The digital pen is a pen type portable device having inertial sensori.e. triaxial accelerometer for general motion sensing, that facilitate the user to interact with computer without any external reference and limitation in working conditions ARM processor,Zigbee module used for wireless communication. This paper present an effective trajectory recognition algorithm that can efficiently select most significant features from the time and frequency domains of acceleration signals collected from inertial sensor and project the feature space into a smaller feature dimension for motion recognition with high recognition accuracy.
Keywords: *MEMS sensor, ARM, zigbee, TRA*

I. Introduction

Explosive growth of miniaturization technologies in electronic circuits and components has greatly decreased the dimension and weight of consumer electronic products, such as smart phones and handheld computers, and thus made them more handy and convenient. Due to the rapid development of computer technology, human–computer interaction (HCI) techniques have become an indispensable component in our daily life. Existing systems proposed or built have various drawbacks which can affect overall system usability like:1)Limitation on range of operation; for communication purpose traditional systems use wired connection, RF modules which restrict the range user can signals to computer. There is a necessity to allow user to operate over longer range.2)Some systems require camera for capturing motion which restricts the user to be in-front of the camera for normal operation and that makes system accuracy depends upon the quality of camera and environmental factors (e.g.: light).3)Few systems restrict user to perform the gesture movement in certain space (eg: a predefined plain) so that it can get the necessary data.So to address these issues, Digital Pen system designed and built such a way that it manages to overcome these limitations with ease.So to address these issues, Digital Pen system designed and built such a way that it manages to overcome these limitations with ease.

To recognizes the trajectories form a pen-type portable device based on MEMS motion sensing technology with triaxial accelerometer that can be potentially used ubiquitously, i.e. can be used on any surface at any time in any orientation that consists of a tri-axial accelerometer, ARM processor, and an Zigbee wireless transmission module. The acceleration signals measured from the tri-axial accelerometer are transmitted to a computer via the wireless module. Users can utilize this digital pen to write digits and make hand gestures at normal speed. The measured acceleration signals of these motions can be recognized by the trajectory recognition algorithm. The recognition procedure is composed of acceleration acquisition, signal preprocessing, feature generation, feature selection, and feature extraction.
In nutshell, the objectives of the system are:

1. The development of an algorithm that can be implemented on any hardware or software platform through low computational power requirements.
2. The development and implementation of a short and efficient algorithm that tries as much as possible to model human perception.

II. Literature Survey

This section covers the overview of existing work done by other authors in this work area. Here we are summarizing information about their proposed systems, and respective pros and cons. This helped us to come up with a concept that allowed us to overcome various problems faced by the existing systems.

Wang et. al. [1] presents a handwritten character recognition system based on acceleration. The character recognition system using a 3-dimensional (3D) accelerometer includes three procedures: Original

signal detection, Signal processing (preprocessing and quantization) and Recognition/classification. In quantization procedure, Trajectory Orientation (TO) and Curve Feature (CF) are adopted and compared. In recognition procedure, Fully-connected Hidden Markov Model (HMM) and Left-Right HMM are both implemented and compared. Many algorithms for gestures or characters recognition were studied, such as Hidden Markov Model (HMM), Bayesian Networks (BN) and Dynamic Time Warping (DTW). Since the objective to be analyzed could be either discrete or continuous, there exist two kinds of HMM, which are Discrete HMM (DHMM) and Continuous HMM (CHMM). The majority researchers use DHMM to find the most feasible activity state which is a lightweight one for math computation.

Shengliet. al. [1] presents a Micro Inertial Measurement Unit (IMU) based on Micro Electro Mechanical Systems (MEMS) sensors is applied to sense the motion information created by characters written by human subjects. The work discussed in this paper focuses on human interactions with computing devices using characters and gesture recognition. There are two major character recognition methods based on different inputs: one is Optical Character Recognition (OCR), which gets data information by scanning the printed text; the other is Dynamic Character Recognition (DCR), which recognizes the characters based on their motion information, such as acceleration, angular velocity and so on.

Meenaakumariet. al. [2] presents an MEMS accelerometer which is based on gesture recognition algorithm and its applications. The hardware unit consists of a tri-axial MEMS accelerometer, microcontroller, and zigbee wireless transmission module for sensing and collecting accelerations of handwriting and hand gesture trajectories. Users will use this hardware module to write down digits, alphabets in digital manner by making four hand gestures. The trajectory algorithm composed of information assortment collection, signal preprocessing for reconstructing the trajectories to satisfy the cumulative errors caused by drift of sensors. So, by changing the position of MEMS (micro electro mechanical systems) we can able to show the alphabetical characters and digits on the PC. The drawback of this system is that it can display the character or numbers in seven segment display format..

Renukaet al.[3] proposed the Online Character Recognition system in which the character is processed while it was under creation. To capture the motions online, the general motion sensor, MEMS which can be operated without any external reference and restriction in working conditions is used. However, motion trajectory recognition is relatively complex because different users have different speed, pressure and strokes to generate a variety of motions. Thus many researchers have tried to narrow down the troubles for increasing the accuracy of handwriting recognition systems. By manipulating the acceleration signals and angular velocities of inertial sensors, some researchers have reduced the error of handwriting trajectory reconstruction. On the other hand, these trajectory reconstructions go through from different inherent errors due to the usage of inertial sensors.

Jeen-Shinget. al.[4] developed a pen-type portable device and a trajectory recognition algorithm. The pen-type portable device consists of a tri-axial accelerometer, a microcontroller, and an RF wireless transmission module. The acceleration signals deliberate from the tri-axial accelerometer are transmitted to a computer via the wireless module. Users can make use of this digital pen to write digits and make hand gestures at normal speed.

This paper has presented a methodical trajectory recognition algorithm structure that can construct efficient classifiers for acceleration-based handwriting and gesture recognition. The proposed trajectory recognition algorithm consists of acceleration acquisition, signal preprocessing, feature generation, feature selection, and feature extraction. With the reduced features, a PNN can be quickly trained as an effective classifier. In this paper they have used 2-D handwriting digits and 3-D hand gestures to authenticate the effectiveness of the projected device and algorithm.

S. Zhanget. al. [5]has proposed an online handwritten character recognition system. The whole system includes three parts: acceleration signal detection, signal processing and recognition by Hidden Markov Model (HMM). In hardware aspect, a mini-board with a three-dimensional accelerometer and a microcontroller is used to get real time acceleration values and send them to a terminal continuously. After effective section extraction and low pass filtering, different quantizing methods based on acceleration orientation are used to quantize numerous data into small integral vectors. At last, use HMM to do the recognition. For the experiments with 10 Arabic numerals, this system shows a high Recognition Rate (R.R.) in the database of limited number of models for every Arabic numeral. This system could be used to reduce the size of handheld devices by discarding number keys and make human computer interaction more convenient and interesting.

J. K. Oh et. al. [6] has proposed a 3-D input medium based on inertialsensors for on-line character recognition and an ensemble classification scheme for the recognition task. The system allows user to write a character in the air as a gesture, with a sensor-embedded device held in hand. The kinds of sensors used are 3-axis accelerometer and 3-axis gyroscope generating acceleration and angular velocity signals respectively. For character recognition, system used the technique of FDA (Fisher Discriminant Analysis). This system used to tried different combinations of sensor signals to test the recognition performance.

After refereeing to various Literature reviews from various authors in this domain, here are the research gaps have been identified:

Along With the advent of computing technologies, specifically in the areas of improved computational speed and reduced system cost with additional functionalities, real-time and virtual interactions between humans and computers have gained significant research and commercial interests. An attractive system have, a portable device embedded with inertial sensors, to sense the activities of human and to capture his/her motion trajectory information from accelerations for recognizing gestures or handwriting. Although so much work has been done, it still seems impossible so far to have a generalized, robust, accurate and real-time approach that will apply to all scenarios. This will require combination of multiple complicated methods to cover all of the difficulties, such as sensor uncertainty, namely sensitivity and offset, contingent error sources such as intrinsic drift of inertial sensors, circuit thermal noise, time discretization, quantization error, vibration, friction, etc. Of course, this will causes low recognition rate and will make it even more time consuming. Research may go more directions, each targeting on some special applications. Some reliable assumption can always be made in a special case, and that will make the handwritten digit and gesture recognition accuracy problem much more simplified. More and more special cases will be conquered, and more and more good application products will appear. As the computing power keeps increasing and network keeps developing, more complex problem may become solvable.

III. System Design

3.1 System components

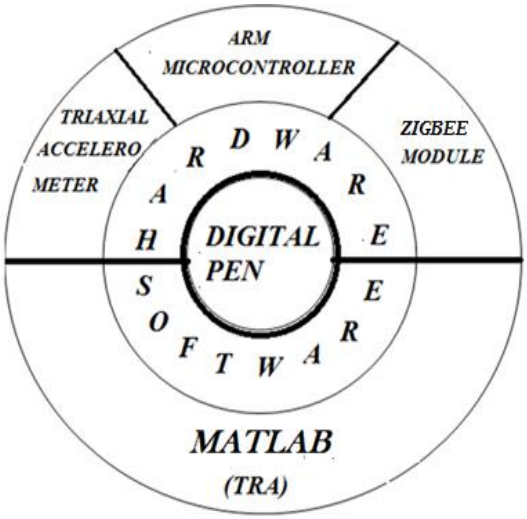


Fig. 1 Pictorial representation of the digital pen system

Digital pen system is an embedded system. It has both hardware and software components. List of the hardware and software component is a mentioned below followed by their significance in overall system.

Hardware components used:

- Tri-axial accelerometer, Zigbee module, ARM Processor, TTL to USB converter, Power supply

Software used:

- Windows version: Windows 7, MATLAB 2012a, Drivers for TTL to USB converter, KeiluVision

Hardware components consist of Tri-axial Accelerometer for collection of accelerated data from the hand gesture, ARM processor with inbuilt ADC (capable of converting the incoming analog signal into digital signal), Zigbee module for wireless transmission. A wireless communication link between a personal computer and the control unit of digital pen, consisting of ARM processor and Tri-axial accelerometer sensor is set up using the CC2500 Zigbee module. At the receiver side Zigbee receiver module use this transmitted data and forward it to computer via TTL to Serial convertor. On PC, application software (TRA) reads the serial data from a predefined COM port (using USB driver for TTL to USB converter component) and uses it for character or gesture recognition.So, by varying the position of Tri-axial Accelerometer (Micro Electro Mechanical Systems) we can show the digits on the computer.

The application software for digital pen is an implementation of the trajectory recognition algorithm, developed and built using MATLAB 2012a. The trajectory recognition algorithm includes the procedures of acceleration acquisition, signal preprocessing, feature generation, feature selection, and feature extraction. The algorithm is capable of translating time-series acceleration signals into important feature vectors. Users can use the pen to write digits or make hand gestures, and the accelerations of hand motions measured by the

accelerometer are wirelessly transmitted to a computer for processing. The algorithm first extracts the time-and frequency-domain features from the acceleration signals and, then further identifies the most important features by a hybrid method: kernel-based class separability for selecting significant features and linear discriminant analysis for reducing the dimension of features. The reduced features are sent to a trained probabilistic neural network for recognition. The limitation of the Trajectory Recognition Algorithm is that it can only recognize a letter or a number finished with a single stroke. MATLAB (MATrixLABoratory) is a numerical computing environment and fourth-generation programming language. Developed by MATHWORKS, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, and FORTRAN. The embedded software component (program loaded on ARM7 processor) has been developed and built Keil software.

IV. Block Digram Discription

The digital pen consists of a tri-axial accelerometer (ADXL335), ARM processor (LPC2138), and a wireless transceiver (CC2500) shown in figure.2.The pen device consists of a tri-axial accelerometer, ARM processor with a 10-b A/D converter, and a wireless transceiver. The triaxial accelerometer measures the acceleration signals generated by a user's hand motions. The ARM processor collects the analog acceleration signals and converts the signals to digital ones by using A/D converter. The wireless transceiver transmits the acceleration signals wirelessly to a proportional to the acceleration in that axis. Acceleration values can be positive, negative or zero. So, the output voltage has a zero bias output. The output given at this point means zero acceleration in that particular axis. So, the zero point voltage is greater than output voltage, it indicates the negative acceleration. The ARM processor integrates a high-performance 10-bit A/D converter and 32-b ARM processor on a signal chip. The output signals of the accelerometer are sampled at 100 Hz by the 10-bit A/D converter. Then, all the data sensed by accelerometer are transmitted to PC wirelessly by a Zigbee transceiver, at 2.4-GHz transmission band with 1-Mb/s transmission rate and at receiver side serial communication take place using TTL to USB converter. Therefore, if a typical AA battery (2000 mAh at 1.5 V) is used as the power of the system, the system requires three batteries simultaneously, and the lifetime is about 67 h. The overall power consumption of the digital pen circuit is 30 mA at 3.6 V.

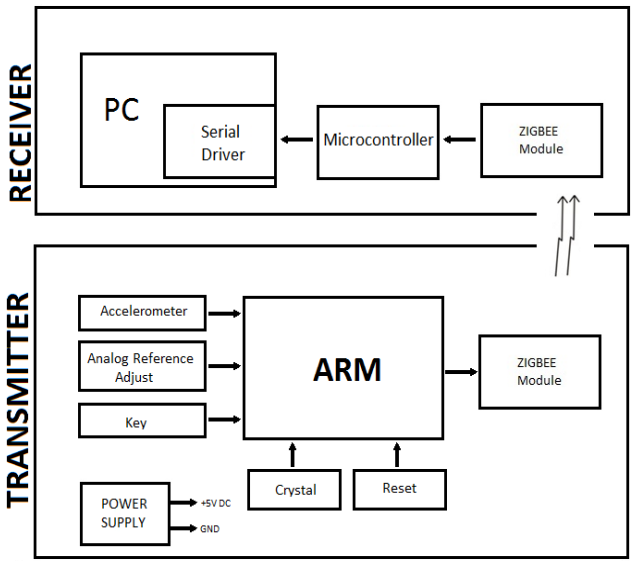


Fig.2 Block diagram of the digital pen module.

The Tri-axial accelerometers (MEMS sensors) are available in various types such as Capacitive, Piezoelectric, Piezoresistive, Magneto-resistive, Heat Transfer, etc. Here in this project we are using capacitive sensor i.e.ADXL335.The ADXL335 is a small, thin, low power, complete 3 axis accelerometer. It can measure the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion, shock, or vibration. The ADXL335 sensor is available in small package. It operates on supply of 1.8 V to 3.6 V.

We have used an additional button can be used to allow users to indicate the starting point and ending point of motion. Power supply circuit built using filters, rectifiers and then voltage regulator, with an AC voltage, a steady DC voltage is obtained by rectifying the AC voltage then filtering to a DC level and finally regulating to obtain a desired, fixed Dc voltage.

V. Trajectory Recognition Algorithm

The block diagram of the trajectory recognition algorithm consisting of acceleration acquisition, signal preprocessing, feature generation, feature selection, and feature extraction is shown in Figure 3

The motions for recognition include Arabic numerals and eight hand gestures. The acceleration signals of the hand motions are measured by a tri-axial accelerometer and then preprocessed by filtering and normalization. Before the filtering and normalization we need to calibrate the inertial sensors to reduce the errors of sensitivity and offset of the sensors first. Then, a moving average filter is applied to remove high-frequency noise from the raw data.

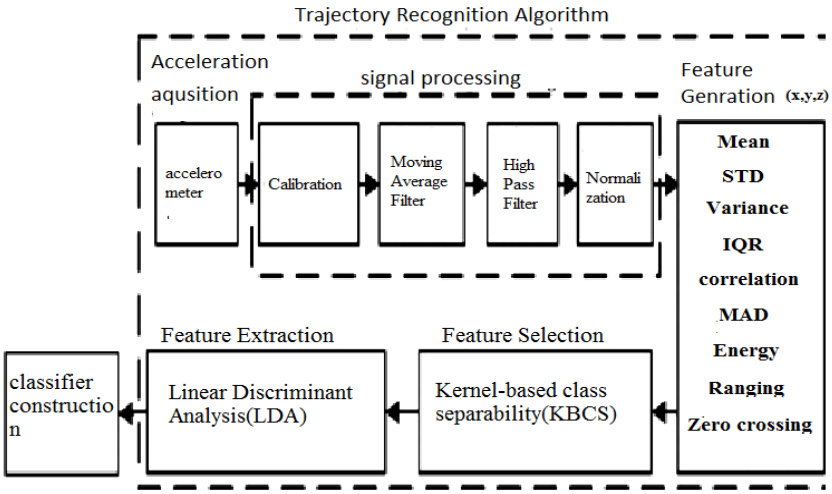


Fig. 3 Block diagram of the trajectory recognition algorithm.

Consequently, the features are extracted from the preprocessed data to represent the characteristics of different motion signals, and the feature selection process based on KBCS picks p features out of the original 24 extracted features. To reduce the computational load and increase the recognition accuracy of the classifier, we utilize LDA to reduce the dimension of the selected features. A discriminant analysis method was also applied in order to select the best components of the feature vector for classification. On the basis of the selected features, a multilayer perceptron with one hidden layer was trained as a classifier. The reduced feature vectors are fed into a PNN classifier to recognize the motion to which the feature vector belongs. For feature extraction there are various type of various type of classifier like PNN, FNN, FDA, HMM, GMM, LDA. They have different recognition rate but in our system we are using PNN classifier because of its higher recognition rate.

The Probabilistic Neural Network was first proposed by Specht[18] .With enough training data, the PNN is guaranteed to converge to a Bayesian classifier, and thus, it has a great potential for making classification decisions accurately and providing probability and reliability measures for each classification. Therefore, the most important advantage of using the PNN is its high speed of learning. Typically, the PNN consists of an Associate input layer, a pattern layer, a summation layer, and a decision layer.

We now summarize the trajectory recognition algorithm in the following steps:

Step1: Acquire the raw acceleration signals from the pen type Accelerometer module.

Step2: Filter out the high-frequency noise of the raw accelerations by the moving average filter in (1) and then remove the gravity from the filtered accelerations by a high-pass filter. Finally, normalize each segmented motion interval into equal sizes via interpolation.

Step3: Generate the time- and frequency-domain features from the preprocessed acceleration of each axis including mean, STD, VAR, IQR, corr, MAD, rms, and zero crossing, ranging in x ,y ,z direction.

Step 4: Select significant features by KBCS.

Step 5: Reduce the dimension of the selected features by LDA.

We have used an additional button to allow users to indicate the starting point and ending point of motion. This can be considered as limitation of the implemented trajectory recognition algorithm as; it can only recognize a letter or a number finished with a single stroke.

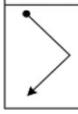
VI. Performance Analysis

Digital pen system describes Accelerometer based gesture recognition method for Digit Recognition. Accelerometer based gesture recognition is one of the widely implemented method in the recognition scenario. We have implemented a 3D input digital pen which works on tri-axial accelerometer to sense human gesture. This digital pen embedded with tri-axial accelerometer, ARM7 processor, and wireless transmitter module. The tri-axial accelerometer measure acceleration signal along 3 axis (X, Y, Z). Accelerated signal process through

processor and serially transmitted through Zigbee transmitter which can be received at remote place zigbee receiver. With the help of MATLAB tool feature vector are generated from received accelerated signal using two extra features zero crossing detector (ZCD) & range to recognize handwritten numeric digit and PNN classifier technique for the best accuracy purpose.

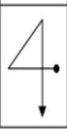
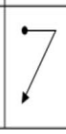
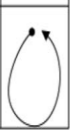
In our application we are using the Trajectory of eight hand gestures shown in Table1 to facilitate digit recognition.

Table 1 Trajectories of eight hand gestures.

1	2	3	4	5	6	7	8
							

The Digit which we want to recognize can be drawn in air using gesture analysis as follow.

Table 2 Pictorial Digit Trajectories

1	2	3	4	5	6	7	8	9	0
									

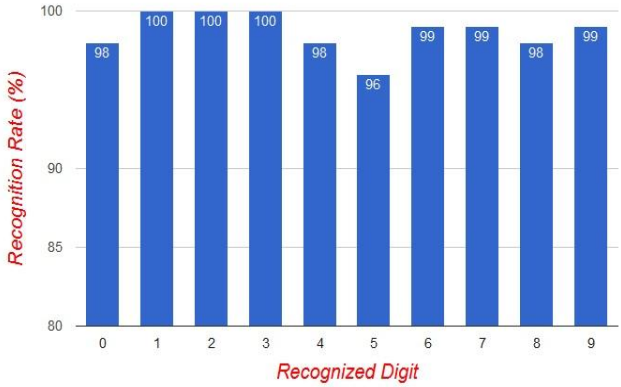
For performance analysis, we collect the database of 10 people that they draw the digit from 0 to 9. Each participant hold the digital pen to draw the trajectories of Arabic numerals as shown in table 2, and the pen tip must touch a table. The confusion matrix for the recognition algorithm by using the PNN classifier shown in Table 3.

Table 3 confusion matrix for the recognition algorithm

Classified as	0	1	2	3	4	5	6	7	8	9
0	98	0	1	0	0	0	0	0	0	1
1	0	100	0	0	0	0	0	0	0	0
2	0	0	100	0	0	0	0	0	0	0
3	0	0	0	100	0	0	0	0	0	0
4	0	0	0	0	98	0	2	0	0	0
5	0	0	0	0	0	96	2	0	2	0
6	0	0	0	0	0	0	99	0	1	0
7	0	0	1	0	0	0	0	99	0	0
8	0	0	0	0	0	0	1	0	98	0
9	1	0	0	0	0	0	0	0	0	99

4.2. Character Success Index

In character success index we plot a graph between recognized digit & recognition rate in percent. In this a single digit we can draw continuously & count how much time it successively recognized.



Graph1 Character success index

4.3 Simulation Result

The following diagram shows the simulation result for digit 1. To show simulated result in matlab we constructed a graphical user interface window which show the recognize digit as well as the value & graph of the X axis & Y axis.

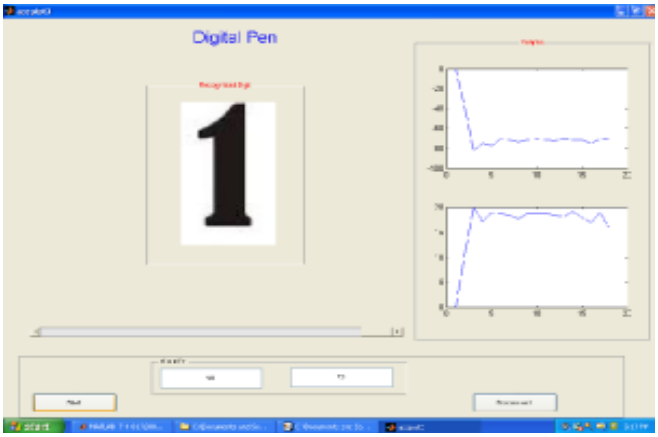


Fig. 4 Digit 1 Recognize On GUI

The above graphical user interface window shows the recognize digit output .In this as the digital pen moves from one end to another end we have to draw the digit then we get recognize digit along with X value & Y value graph. We can use this project work in the various applications where gesture recognition is used. The application area like Providing the security using gesture recognition that means operating the system with predefined digit stored in the database & the digit will act as a authenticate digit of accessing the system & second any other digit will act as a closing the system.

VII. Conclusions

5.1 Conclusion

The digital pen consists of a tri-axial accelerometer, an ARM processor, and a Zigbee wireless transmission module; for sensing and processing the handwriting and gesture trajectories acceleration signals. System provides systematic trajectory recognition algorithm framework that can construct effective classifiers for acceleration-based handwriting and gesture recognition. The proposed trajectory recognition algorithm consists of acceleration acquisition, signal preprocessing, feature generation, feature selection, and feature extraction. With the reduced features,a PNN can be quickly trained as an effective classifier. In the performance analysis, we used 2-D handwriting digits and 3-D hand gestures to validate the effectiveness of the proposed device and algorithm. At its core system uses the Trajectory recognition algorithm & PNN, to match of gesture. For this purpose we have devised a system which gives the 98.2 % efficiency in recognition of gesture, concluded from database & character success index. This result encourages us to further investigate the possibility of using our digital pen as an effective tool for HCI applications.

The challenge with On-line character recognition is the development of a system that can recognize the characters in real-time. This requires a system that requires very simple and short calculations. If not, the time taken to recognize the characters will render the system useless .Contributions of this system include the following: 1) the development of a portable digital pen with a trajectory recognition algorithm, i.e. with the digital pen, users can deliver diverse commands by hand motions to control electronics devices anywhere without space limitations, and 2) an effective trajectory recognition algorithm, i.e., the proposed algorithm can efficiently select significant features from the time and frequency domains of acceleration signals and project the feature space into a smaller feature dimension for motion recognition with high recognition accuracy. By means of this technology we can put pen on surfaces & display the characters not including the keyboard for applying the human interaction to the computer.

5.2 Future scope

The development of the portable device that can be used to generate commands by hand motions to control electronic devices without space limitations. The acceleration made by the hand motion is measured by the accelerometer are wirelessly transmitted to the computer. The system uses single stroke handwriting algorithm.

The Digital pen can be used for multi stroke handwriting by making some modifications in algorithm. With the multi-stroke handwriting user can write the full sentence with normal speed. In this system the pen

section can be interface with microcontroller wirelessly or microcontroller can be installed inside pen section by using system on chip technology to fabricate a microchip. Future enhancement in the system is: Wi-Fi can be connected the system for internet connectivity. The GSM modem can be connected for SMS system where SMS alert can be done.

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