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ACCELEROMETER BASED DIGITAL PEN FOR HANDWRITTEN DIGIT AND GESTURE RECOGNITION

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ABSTRACT

In the today's world of fast changing technology, there is also rapid development of computer technology. Human computer interaction commonly known as HCI, technique is one of that which becomes an indispensable component of our daily life. HCI includes computer science, design, media studies, the term was popularized by Stuart k. card & Allen Newell in 1983. Here we are going to use simple pen as input device which track trajectories in 3-D space by using sensor name as accelerometers & gyroscopes. An Error compensation algorithm which is based on zero velocity compensation is developed which help to reduce errors in acceleration to acquire accurate trajectory. This process is done in signal processing section which comprises of calibration, moving average filter, High pass filter which reduce high frequency noise & drift error, offset respectively. The output of signal processing is then fed to feature generation, feature selection & feature extraction to takes raw unstructured data & generate feature by removing low value words, to reduce set of feature & to create new feature from function of original feature respectively. Recently to improve its accuracy some researcher starts more research to reduce the error of trajectory reconstruction.

KEYWORDS: Triaxial Accelerometer, Probabilistic neural network, Linear Discriminate Analysis, Feature Selection, Feature Generation, Feature Extraction.

INTRODUCTION

To reduce the dimension and weight of consumer electronic product, there is explosive growth for miniaturization technologies in electronic circuit and related components which made them handy & convenient from consumer point. Human computer interaction which is used in this project is particularly focus on interfaces between computer and users which act as open ended dialog. We can use sensors like Novel sensor, DT6 sensor to detect activities of human and to capture his/her trajectory motion information from gestures or handwriting. But we used accelerometer sensor adxl335 in this project due to its measuring capability of static as well as dynamic acceleration.

A significant advantage of this sensor is that they can be operates without any external reference & limitation in working condition. However there is one problem in recognition of motion trajectory is that different user has different style & speed to generate various motion trajectory and gesture pattern.

Recently due to the advance research done in this field, its accuracy increases at satisfied level as well as its error of handwritten trajectory also reduced to some extent which was present in previously research due to use of various algorithms. Still the reconstructed trajectories have some intrinsic error and offset. So, many of researchers have focused on developing an effective algorithm which will reduce inertial error and offsets to improve the recognition accuracy. In this, there is main problem to adjust the offset which were generated at the time of gesture recognition.

In this project, we are going to use simple pen as an input type to track the trajectories in 3-D space with the help of sensor accelerometer & gyroscopes. An algorithm is used to compensate error which was developed to reduce acceleration error to acquire accurate reconstructed trajectory. Kalman filter is also used in this to compensate orientation of the proposed digital writing instrument. In this we try to estimate the orientation of our instrument that is pen, so that we can reconstruct motion trajectories properly to estimate the hand gesture.

RELATED WORK

Now Days, some studies have been focused to develop the performance of digital pens for the purpose of trajectory recognition and human computer interface. Milner has proposed an alternative method for handwriting recognition

known as tablet based handwriting recognition. He used two dual axis accelerometer in his experiment. This accelerometer are mounted on the side of digital pen which generate time varying x and y axis acceleration for handwritten gesture and pattern recognition. In this, author employed HMM concept with down sampling and banpass filtering which passes the frequency within range and reject frequencies outside that particular range. Down sampling reduces the sampling rate of signal. In this system milner used the down sampling to reduce the size of data that was gathered during the process of writing the digits for the classification of seven handwriting words. In his system after using band pass filter and down sampling he got best result as 95.8 % for recognition when number of status for HMM is equal to 60 %. That was best result got by milner in recent working on digital pen.

Fisher discriminant method which is generally known as generalized discriminanrt analysis is used to map the non linear behavior of hand motion recognition with different combination of sensor signal which used to test the recognition performance. Here sensor used is accelerometer sensor which is triaxle and triaxle gyroscope to know the position of hand while writing. When all present six axis raw signal were used as input at that time recognition rate of recognizer was 95%.

The third method in digital pen is that use of trajectory estimation algorithm to recognize gesture which consists of gesture input device. This method was proposed by cho. To reconstruct the trajectories of numeral digits, the trajectory estimation algorithm based on inertial navigation system was developed by cho. He used the Bayesian network to recognized and reconstruct trajectories.

Due to use of baysian network, average recognition rate was 99%. Bayesian network is probabilistic graphical model which represent set of random variable and there conditional dependencies using directed acyclic graph. Here set of random variable is considered as input from digital pen. Zho proposed uIMU method for 2-D handwriting application. It extract discrete cosine transform which extract feature from x and Y-axis. Angular velocity used unsupervised self organization map to classify 26 english character and 10 numerical digit. DAG in Baysian represents random veriable in baysian sense.

PROPOSED APPROACH

A. Hardware Design of Digital Pen.

Digital pen mainly consists of three stages, Digital pen as input, processing through hardware part and we get output from software. This is combination of human and software so it is called as human computer interface. In this, Digital Pen uses traixial accelerometer model no. is LIS3L02AAQ3. Actually this is a sensor which is placed at the top of pen to recognize handwritten gesture. Another thing is microcontroller which is C8051F206 with 12-b A to D convertor. Third is wireless transceiver of nRF2401. In this way its hardware is design to get maximum performance. The following is the basic block diagram of the system.

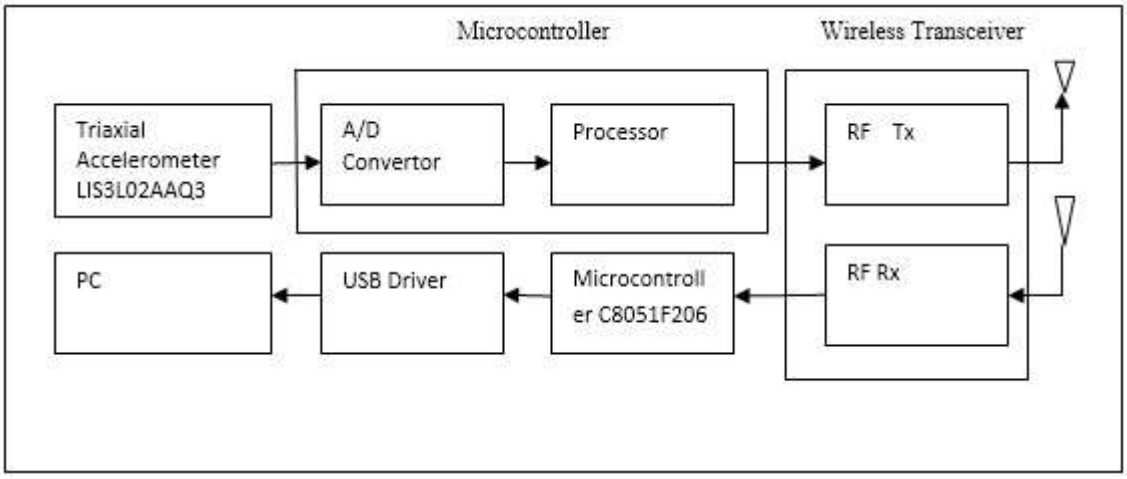


Figure 3.1: Block Diagram of Digital Pen module

In above diagram, we are taking input from sensor. The main function of accelerometer sensor is to detect the position of device on earth which is given by g = 9.81 m/s^2. Here device is our pen. This sensor detects and monitors vibration.

In our case, it detects position. Accelerometer sensor is used in tablet computers and digital camera also so that image on screens is always display upright. Microcontroller collects analog acceleration by pen which is analog one. This signal gets convert into digital through A to D converter. Here wireless transceiver transmits the acceleration signal and in the last step this signals send to computer or laptop.

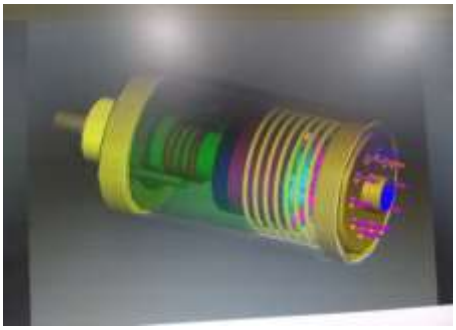


Figure 3.2 Accelerometer Sensor

Trajectory Recognition Algorithm

The word Trajectory means that "the path followed by object moving under the action of given force." Here the object is hand and its path followed by trajectory with sensor. This motion of hand for recognition may include small letter numerals. These generated signals are measured by triaxial accelerometer. The output of triaxial accelerometer is processed by filter and normalization stage. Parallel, features also generate in this process. These features have to extract to improve the performance of pen. So in this features are extracted from data. This helps us to represent the characteristics of motion signals. In this, kernel based class reparability is used to selection of features. The trajectory recognition algorithm is classified into three phases name as feature Generation, Feature selection and Feature Extraction.

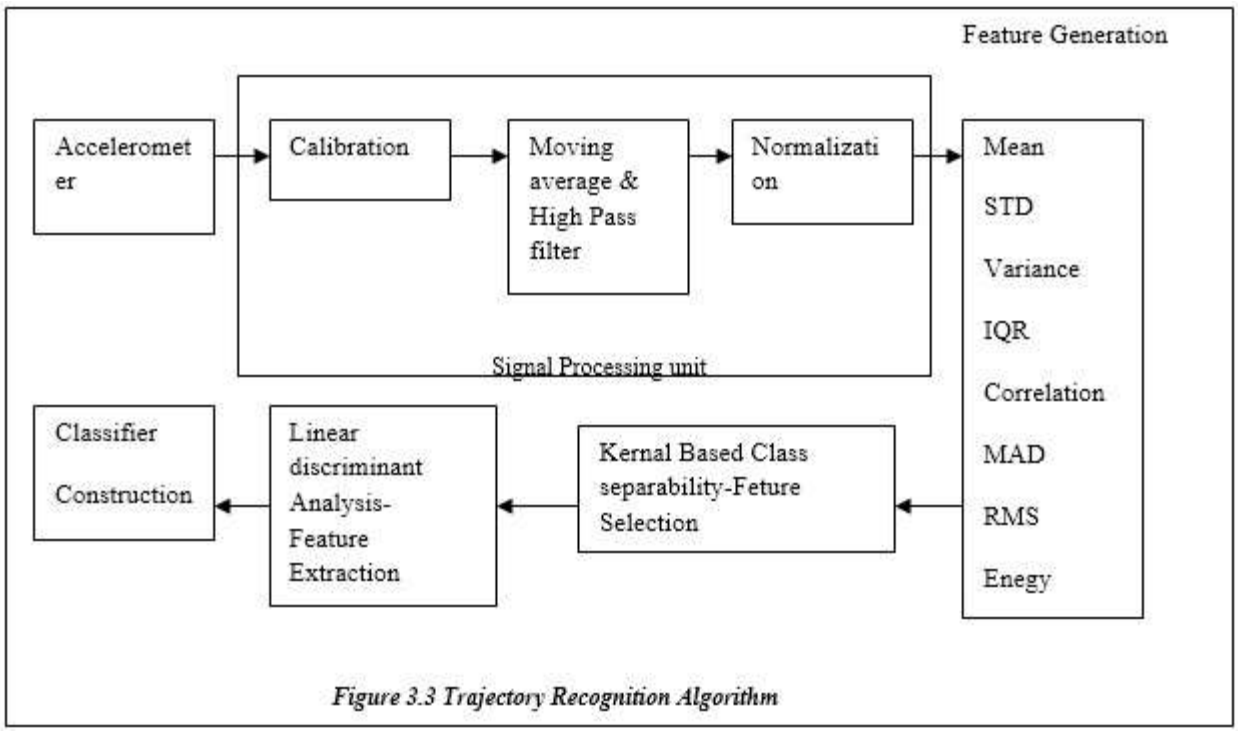


Figure 3.3 Trajectory Recognition Algorithm

Figure 3.3 shown is the block diagram of trajectory recognition algorithm which consist of acceleration acquisition, signal processing, in depth step of feature generation, feature selection feature extraction which were discussed earlier.

Above diagram is basically divided into five steps name as data acquisition through Accelerometer, signal processing section which uses MAF, HPF and calibration, Feature Generation which compromises eight character mention below in depth , next is feature selection and feature extraction to extract data with the help of LDA. Lineardiscriminate analysis helps us to reduce dimension of feature which is selected. LDA also help us to reduce computational load as well as to increase recognition accuracy. This feature which is reduced by linear discriminate analysis is then fed to probabilistic neural network classifier. Here in PNN classifier, this reduced Features are send to recognize the motion to which the feature vector belongs. We can elaborate detailed procedure for trajectory recognition as per bellowed algorithm.

Signal Processing Stage:
In this signal processing stage, the raw signals which are generated by hand motion and detected by digital pen are collected by microcontroller. The noise is generated during collection of data as human hand always trembles while writing or moving. This signal processing section consist of calibration, filter section of moving average and high pass filter and the normalization stage. As we know that moving average filter is used to reduce the high frequency noise which were generated at the time of accelerations. Before this the generated accelerations are calibrated. This calibration removes the drift errors and offsets which were generated at the time of collection of raw signal. The filter is expressed as:

$$y[t] = \frac{1}{N}\sum_{i=1}^{N-1} x[t+1]$$

Where as x[t] = input signal, y[t] = output signal, N= number of points in average filter. Here N=8.this value 8 is comes from empirical taste. It is taken to achieve best recognition result of moving average filter. To remove the gravitational acceleration from filtered acceleration we used high pass filter. After filtering the data we segment each movement to extract motion interval. This we have to do because speed of writers may vary from person to person. Using interpolation we normalized each segment motion interval into equal size. Once this process gets completed, then required feature can be extracted. In this way signal processing stage is used which uses calibration, moving average filter, high pass filter.

Feature Generation:
Feature generation is the process of taking raw, unstructured data and defining features for potential use in our statistical analysis. It is also known as variable selection, attribute selection or variable subset selection. With feature extraction, we get characteristics of different hand movement signal from x,y,z axis include eight signal that is Mean, STD,VAR,IQR,MAD,RMS and Energy.

The characteristics of different hand movement signals can be obtained by extracting features from the preprocessed x, y, and z axis signals, and we extract eight features from the triaxial acceleration signals, including mean, STD, VAR, IQR, correlation between axes ,MAD, rms, Correlation and energy . They are explicated as follows. All above eight features are explained as bellowed through implementation of this, we can recognize gesture in some manner.

1. Mean: Mean in this project is DC signal value of acceleration signal from each hand motion which is given as follows,

$$\frac{1}{w}\sum_{i=1}^{w} x$$

W= Length of each hand motion.

2. STD: Standard is the square root of variance. Here we got the value of STD from variance square root. Formula for STD as bellowed.

$$STD = \sqrt{\frac{1}{|W|-1}\sum_{i=1}^{|W|}(x_i - m)^2}$$

3. VAR : VAR is given as

$$VAR = \frac{1}{|W|-1}\sum_{i=1}^{|W|}(x_i - m)^2$$

Xi=acceleration instance
M = mean value of xi from STD and VAR.

4. IQR
To obtain a measure of variation, we find here interquartile range or IQR. This is given by formula Q3-Q1.

This range ree dispersion of data and it eliminated the influence of outliners in the data when different classes have similar mean value.

5. Correlation :
Correlation is computed or it is the ration of covariance to product of STD for each pair of axes. With the help of correlation, we translate discrinating motions in only one direction.

$$corr = \frac{\mathrm{cov}(x,y)}{\sigma_x \sigma_y} = \frac{E\left((x-m_x)(y-m_y)\right)}{\sigma_x \sigma_y}$$

E = expected value of σx
σx = STDs
mx, my = expected values of x and y.

6. MAD: it is mean absolute deviation. MAD is used to measure the variability of univariate sample of quantitiative data. It may also refer to population parameter. It is also refer to the set of data is the average distance between ech data value and the mean. In this gesture recognition, we find MAD by finding the distance between each data value and mean.

General equation for mean absolute deviation is given as below:
MAD= median (| xi – medianj (xj)

7. Root mean square value is given by :

$$rms = \sqrt{\frac{1}{|W|}\sum_{i=1}^{|W|} x_i^2}$$

Xi=acceleration instance

m = mean value of xi

8. Energy:
Energy is calculated as the sum of magnitudes of squared discrete fast fourier transform components of the signals in a window. Its equation is given as

$$Energy = \frac{1}{|W|}\sum_{i=1}^{|W|}|F_i|^2$$

Fi = ith FFT component of window
|Fi| = magnitude of Fi
Using above eight feature selection, we recognize hand gesture motion. After this we are get 24 features. In this we get large amount of extracted feature. This data is so huge to recognition. So to reduce feature, we used KBCS that is kernel based class separability and then fed to LDA, linear

Feature Selection :
Once feature is generated, then feature selection process is started. This method reduces the set of feature and keep only useful feature. Many approaches have been proposed to select useful feature. In this, we used

KSBC feature selection method. Apart from KSBC there are c-modified least squares classifier method is also available. KSBC method is originally developed by wang.
The KSBC computed as bellowed equation:
Let (x, y) ∈ (Rd × Y) which represents a sample,
Rd = d-dimensional feature space,
Y = the set of class labels,
The size of Y = the number of class c.

Using above method, we project the samples on a kernel space. miθ is mean vector for the ith class in measured kernel space. Whereas ni denotes the number of sample in ith class. SBθ denotes the class between scatter matrix in the same that is kernel space. θ(.) is nonlinear mapping from feature space Rd to a kernel space κ. tr(A) represents the trace of a square matrix A. bellowed given equation were used to represent feature selection :

$$tr\left(S_B^\phi\right)=tr\left[\sum_{i=1}^{c} n_i\left(m_i^\phi-m^\phi\right)\left(m_i^\phi-m^\phi\right)^T\right] \qquad tr\left(S_W^\phi\right)=tr\left[\sum_{i=1}^{c}\sum_{j=1}^{n_i}\left(\theta(x_{ij})-m_i^\phi\right)\left(\theta(x_{ij})-m_i^\phi\right)^T\right]$$

$$=\sum_{i=1}^{c} n_i\left[\left(m_i^\phi-m^\phi\right)\left(m_i^\phi-m^\phi\right)^T\right] \qquad =\sum_{i=1}^{c}\sum_{j=1}^{n_i}\left[\left(\theta(x_{ij})-m_i^\phi\right)^T\left(\theta(x_{ij})-m_i^\phi\right)\right].$$

We adopt the BIN technique to maximize class separability as search strategy. In this technique criteria is applied to each feature so that feature with larger values of the given criteria are selected.

Feature generation algorithm considers a single brute force selection over a large set of all features which are of all different types. To apply appropriate selection method, we used categorized the different feature in this. We extracted relevant feature. In this we designed a classifier as a last stage over a final stage of features.

FEATURE EXTRACTION

It is necessary to test transformation after generating features. We select subset from this pool and derived features for use. Data contain non linear information. For such huge amount of pattern recognition, Linear differentiate analysis is used in feature extraction stage. LDA is an effective feature extraction technique which is also known as dimensionally reduction method. This method transform original feature set into lower dimensional feature space. Actually LDA is Fishers linear discriminant method used in feature extraction. Its resulting combination is used as a linear classifier. Working of LDA is closely related to analysis of variance and principal component analysis.

Sw is scatter matrix and SB is between class scatter matrix are introduce as follows:

$$\mathbf{S}_B=\sum_{i=1}^{N} n_i(\mathbf{m}_i-\mathbf{m}_{all})(\mathbf{m}_i-\mathbf{m}_{all})^T$$

Where ni = The number of samples in the ith class,
xj(i) ∈ Rd = the jth sample of the ith class.
d = ith dimension of the feature space, n
N= the total numbers of the samples and classes.
mi = The mean of the ith class,
mall is the mean of all classes.
SWi = The covariance matrix of the ith class,
SW = The sum of the covariance matrices,
SB = The sum of the squared distances between the mean of each class and the means of all classes.
As discussed above, the fundamental concept of LDA is to maximize Fisher criteria to search for the most efficient projection matrix w.

$$J(\mathbf{W})=\frac{\mathbf{W}^T\mathbf{S}_B\mathbf{W}}{\mathbf{W}^T\mathbf{S}_w\mathbf{W}}$$

WTSWW & WTSBW = New within class scatter & between class scatter in the new feature space.

Transformation matrix W is utilized in order to achieve maximal discrimination in new feature space. Feature vector y can be calculated by equation y =WT x. These reduced features fed to Probabilistic neural network classifier to recognize different hand movements.

CLASSIFIER

The last stage in this system is classifier which uses PNN network. It is feedforward neural network which is derived from Bayesian network and algorithm Kernal Fisher discriminant analysis. PNN is introduced by D.F. Specht in 1990. In this PNN network, the operation are organized into four layer namely as input layer, hidden layer, pattern layer or summation layer and output layer. Advantage of PNN is that the much faster than multilayer perceptron networks, can be more accurate the multilayer perceptron networks and its approaches to bayes optimal classification.PNN is a great potential for making classification decision accurately and providing probability for each classification. PNN only need one epoch to adjust the weight and biases of the network architecture.

A. Input layer: each neuron from this layer represents a predictor variable. It standardizes the range of values by subtracting the median and dividing by interquartile range IQR that is q3-q1. The neurons from this layer convey the input feature x of the second layer directly.

X=[x1, x2….xp] T

p = number of the extracted features.

Pattern layer: pattern layer contain one neuron for each case from training data set. This layer stores the values of predictor variables from PNN network. A hidden neuron computes the Euclidean distance of the test case from neuron centre point and kernel function using sigma values. Number of neuron in this layer is NL. The output of the neurons can be calculated as bellowed :

$$\varphi_{ki}(x) = \frac{1}{(2\pi)^{d/2}\sigma^d} \exp\left(-\frac{(x-x_{ki})^T(x-x_{ki})}{2\sigma^2}\right)$$

xki = Neuron Vector.

σ = Smoothing Parameter.

d = Dimension of pattern vector x & φki is the output of pattern layer.

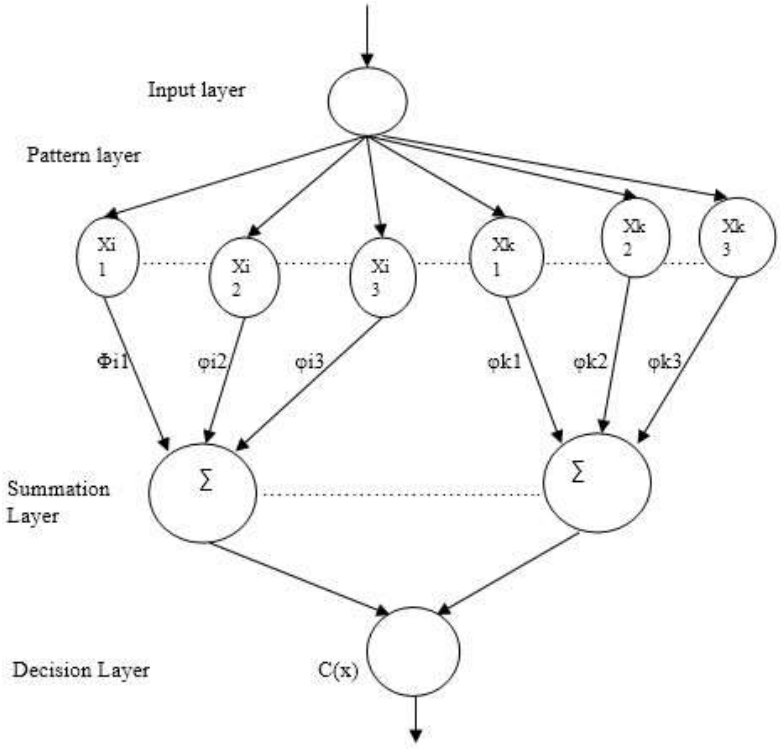


Figure 3.4 PNN Network Structure

C. Summation Layer: The actual target category of each training case from PNN network is stored with each hidden neuron. The weighted value coming out of hidden neuron is fed only to pattern neuron which corresponds to hidden neuron category. In this layer, contribution for each class of inputs is

summed to produce the output as the vector of probabilities. The output of kth neuron is given by:

$$p_k(x) = \frac{1}{2\pi^{d/2}\sigma^d} \frac{1}{N_k} \exp\left(-\frac{(x-x_{ki})^T(x-x_{ki})}{2\sigma^2}\right)$$

D. Decision Layer: The last layer is the decision layer. This is the output layer which compares the weighted votes for each target category accumulated in the pattern layer and uses the largest vote to predict the target category.

C(x)=arg max {pk(x)}, k=1,2,…,m
m = Denotes the number of classes in training samples & c(x) is estimated class of pattern x.
The output of PNN is the label of the desired outcome defined by users.

RESULT AND DISCUSSION

The outcome or efficiency of above used trajectory recognition algorithm is checked by two experiments

1. Gesture recognition technique in which algorithm is used to recognize gesture.
2. Handwritten digit recognition to gather data from handwriting.
3. Acceleration acquisition, signal preprocessing, feature generation, feature selection and feature extraction, this are the proposed trajectory recognition algorithm
4. We implemented different types of combinations and permutations for feature selection and extraction to recognize gestures and digits. This result is then comparing with various engineering techniques like feedforward neural networks.
5. Gesture Recognition technique:
   In this method hold the pen in such a way that that pen performs eight hand gestures in a 3-D space. This gesture shown as bellowed.

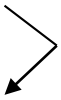
1	2	3	4	5	6	7	8
							

Table 4.1 Trajectories of eight hand gestures

Handwritten Digit recognition: in this technique we have to generate the data through the input device that is pen. Like others dos and donts, here are also some donts. In this we have to hold the pen tip which must have to touch to some reference like table, whiteboard, and note book. Once we get acceleration signal, then this signal are transmitted through sensor for processing through proposed trajectory recognition algorithm. Here in our experiments we have taken some acceleration signals for numerical value 0 as shown below.

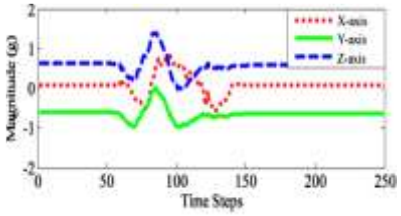


Figure 4.2 acceleration digit for 0

We have plotted the graph magnitude verses time steps. As we discussed above, there are three axis x,y,z. for each axis we get different result with less or more accuracy. This is result of simple calibrated acceleration. But to improve the accuracy we send this data from moving average filter and band pass filter to compensate its offsets and noise. We get bellowed result when we pass these signals through filters with more accuracy.

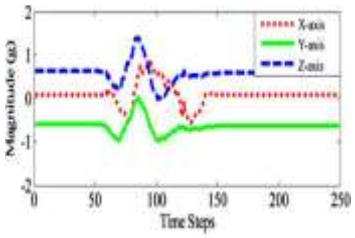
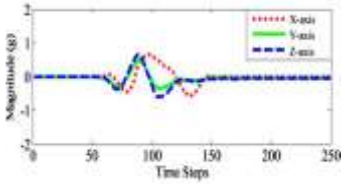


Figure 4.2.1 Moving average filter for 0



4.2.2 high pass filter for 0

In this way, we generate and compare the signals for each numerical digit and its result gets compared to improve pens accuracy.

For digit 7 we get signal as shown in bellowed figure.

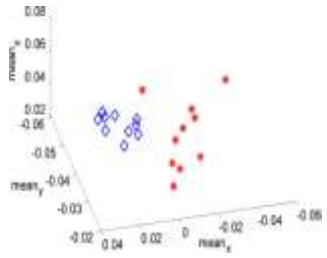


Fig.4.4 high pass filter for digit 7

If ten numerical digits from 0 to 9 are to be classified, then we used LDA and its feature extraction is nine. In this we can collect the data of alphabetic also. By using KBCS and LDA technique, the best recognition rate is 96.8%. But it is less that to of alphabets. In case of alphabet its accuracy is much less at about 87%.

To improve its accuracy, we combined KBCS and LDA which helps us to reduce feature dimension in this system. Thirteen feature were selected by KBCS and then send to LDA. Table 4.1.1 shows average recognition rates are given.

Feature selection method	KBCS	x	KBCS
Feature extraction method	X	LDA	LDA
Recognition rate	82	97	98

Table 4.2.3 Average recognition rate

Here we used total CPU runtimes for applying different combination of feature. The burden of computational load increases the accuracy of classification as shown in table 4.2.3

Method	PNN	KBCS+PNN	LDA+PNN	Kbcs+LDA+PNN
Feature Dimension	25	12	9	9
Total CPU time	17	16.78	15.35	15.40
% of improvement	-	0.52%	6.29%	6.40%

Table 4.2.4 Classifications of different technique

Above table shows the average recognition rate of PNN outperforms that of the FNN. The KBCS select 12 out of 24 and LDA reduces the dimension of features.

In my experiment, features include meanx, correlation, meany, meanz, MADx,MADy, MADz, IQRx, IQRy, IQRz, rmsx and rmsz were selected by KBCS. In this way by using KBCS, LDA, PNN combination we can recognize hand trajectories for game controller, TV remote control and presentation pointer.

CONCLUSION

This paper consists of a systematic recognition algorithm framework that helps us to reconstruct the acceleration based handwriting and gesture recognition. This algorithm consists of acceleration acquisition, signal preprocessing, feature generation, feature selection and feature extraction which help to select appropriate data with reduced feature. The overall handwriting digit recognition rate was 98% and alphabet recognition rate is 82%. This result motivate us to do further investigation on accelerometer sensor to improve its accuracy for alphabet recognition for human computer interface.

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