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3-D Drawing Digital Pen

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Abstract

World is turning into digital, everything in today's life needs to be digital. However human cannot interact digitally all the time. So Analog-to-Digital and Digital-to-Analog transform is forever. Unfortunately, innovations for converting 3-dimensional real-world objects into digital are limited to television-cameras only. So some technologies like digital pens are required to deal with the 3D real-world peculiarities. Even the most recent digital pens too operate in 2-dimension. "Wireless 3-D Drawing Digital Pen" is the required solution for the transform between the two domains. The proposed device can create a 3-Dimensional image on computer screen by drawing the object in the air virtually. This device can also recognize handwritten digit and gesture trajectory in 2-dimension. It is microcontroller based system with various user interfaces, memory and wireless communication which enables it to support real time operation.

Keywords

Digital pen,3D image, gesture trajectory recognition, real to digital world.

1. Introduction

An accelerometer based digital pen is not a new concept by its name but definitely a new and innovative one with its idea of 3-D image drawing; as there is no such device available in the market till date which can create a 3-Dimensional image on computer screen by drawing the object in the air virtually with the help of interactive handheld wireless input device like a *stylus* or *mouse* or simply a *digital pen.*

Besides 3-D object drawing, this digital pen can also be used for handwritten digit and gesture trajectory recognition applications. This new version of "Human-Computer Interaction" technique makes it much convenient and easier to communicate between the 3-D real world life and digital world. For present, though it is possible to create the 3-D figures with the help of computers, it is not as easy as it requires user to have great skills and imagination power. However with the help of this device, user with his logic to draw a required pattern in the air can have the required object in 3 dimensions on the computer screen. The proposed device can not only recognize the regular geometric shapes but also draws the different real world on screen easily, no matter how skillful you are withdrawing. This device is also capable of replacing the existing Note – Taker as we are having wireless data transmission facility and built in memory which means no need to carry diaries or *PDA*s.

Background and Relevance

Pen-based computers allow users to write/input directly on a screen. The need to write directly on a screen reveals the importance of handwriting in daily life and demonstrates that the applications of pens are expanding with the development of technology. Touch pens allow user to write directly on a computer screen. This study investigates the touch pen use in three sections. First, observations of users' handwriting during three screen tasks: writing, pointing-and-clicking and drawing. Second, examinations of the design and development of touch pens based on observed results and related design theory. Third, this study compares the five-point grip pen (FPGP) with the common touch pen.

In the past decade many researchers have investigated the use of MEMS accelerometers and gyroscopes in intelligent consumer devices. They function as inclinometers or as inertial measurement units (IMUs) for gesture reconstruction and recognition. Among these devices, a computer pen for the simultaneous writing on a piece of paper and on a computer screen without using a reference system, such as a PC tablet.

This computer pen has two modes of operation and uses two mechanical sensing principles. The writing mode represents the condition when the pen tip is in contact with the paper, and the air mode represents the operation when the pen tip is in slight contact with the paper or when the pen moves freely in the air. During the writing mode a friction model, based on force sensing using a specially designed sensor is used to determine the position of the pen tip on the paper, whereas the combined inertial and magnetic principles are used in both modes to determine the pen's orientation and to determine the position of the pen tip when it is in the air mode. In general, the inertial principle involves use of the sensors such as MEMS accelerometers and gyroscopes, the principle of operation of which is based on their sensitivity to the inertial forces and it uses only their outputs for further processing. However, in this case, the inertial measurement had insufficient information about the angular movement of the pen. The consequent error in the separation of the gravitational and linear accelerations resulted in a substantial positional error for the pen tip, which grew quadratic ally over time. Therefore, this research concentrates on a further improvement to the gesture reconstruction during the air mode, taking into consideration the existing solutions for similar electronic devices.

2. Organization of Paper

Section 1 gives the introduction to the idea of 3D drawing. Section 3 of paper explains the related work done in accelerometer based digital pen. Section 4 explains methodology which is to be implemented for 3-D image drawing, Section 5 gives detailed case study of Trajectory Recognition. Section 6 gives the conclusion of the study and finally references are been enlisted.

3. Literature Review

When using either six degrees of freedom (DoF) IMU or a gyroscope-free IMU, the error limitations of the inertial positioning based on miniaturized sensors forced researchers to apply additional post-processing steps to improve the accuracy of the reconstruction or the efficiency of the recognition procedures of commercial electronic devices. The most important problem to be solved out was the extraction of a useful parameters from the inertial signal. There were approaches made by *Yang et al*[2], which benefit from the gravity interference on the sensing axes inand observe the standard deviation of the acceleration and the angular rate signals. Furthermore, an alternate and better method, compared to that of *Yang[2]*, was reported by *Lim et al*, which is known as Extreme Point Sampling (EPS). The detected starting and finishing points of the gesture are crucial for the efficiency of the procedures used to compensate for the orientation and the acceleration errors leading to positional drift after the double integration of the acceleration. Procedures called attitude compensation and zero-velocity compensation were described by *Yang et al* and by *Bang et al,* which had added remarkable improvements. In the mentioned researches, the inertial principle was confirmed to be useful for single, uniform strokes over a short time period.

Another way to improve the gesture reconstruction is to calibrate the IMU, as this procedure can minimize the errors caused by the limited performance of low cost MEMS inertial sensors concerning typical parameters, such as sensitivity, cross-sensitivity, misalignment, bias and broadband noise. Latest research treats the accelerometer as an inclinometer. And also consider as a sensor for measuring the linear accelerations along its axes. Therefore, the calibration should be based on the modelling of the accelerometer's output, irrespective of its function.

4. Methodology

The hardware modules of the proposed 3-D drawing digital pen are shown in Fig.1

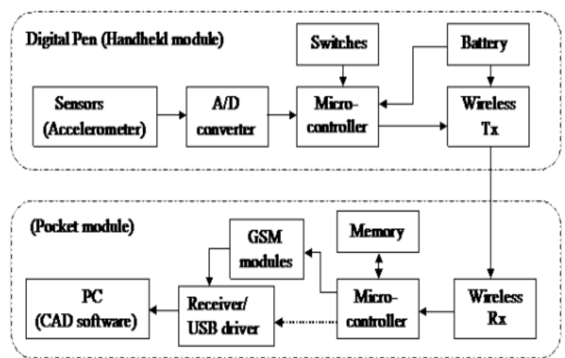

Fig.1 Block diagram of proposed digital pen

As shown in the above block diagram, the proposed device consists of two modules- a pen like module and a pocket module for sensing and collecting accelerations generated out of the movement in air and handwriting and gesture trajectories recognition respectively. The proposed handheld module (Pen) composes of the sensors - accelerometer and gyroscope, data acquisition, signal pre-processing and transmitting (RF or 802.15.4) block with rechargeable battery unit.
In Pocket module along with micro-controller (MSP430) there is a receiver block, a power supply, memory and USB driver to provide wired transmission of data between pocket module and PC. A GSM module can also be used to achieve long range wireless communication for outdoor applications.

Users can use the pen to write digits or make hand gestures, and the accelerations of hand motions measured by the accelerometer that are wirelessly transmitted to a computer for real time trajectory recognition. At the PC side the received data is processed and displayed on the screen on a specially designed Graphical User Interface or 3-D drawing application software.

5. Case Study

A. Trajectory Recognition Algorithm

Fig.2 shows the "Trajectory Recognition Algorithm" [1] which consists of acceleration acquisition, signal preprocessing, feature generation, feature selection and feature extraction blocks.

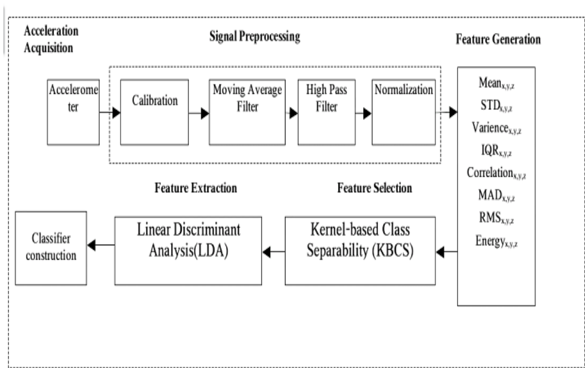

Fig.2 Trajectory Recognition Algorithm

The acceleration signals of the hand motions are measured by a tri-axial accelerometer and then pre-processed by filtering and normalization. Consequently, the features are extracted from the pre-processed 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. The feature vectors after reduction are fed into a PNN classifier to recognize the respected motion to which the corresponding feature vector belongs. We now introduce the detailed procedure of the proposed trajectory recognition algorithm as follows.

B. Signal Conditioning

The raw acceleration signals of hand motions are generated by the accelerometer and collected by the microcontroller. It is observed in all human beings that our hand always vibrates or shakes slightly while moving, which introduces certain amount of noise. The signal pre-processing unit consists of calibration block, a moving average filter, a high-pass filter, and normalization block. First, from the raw acceleration signals, drift errors and offsets are removed and the accelerations are calibrated to the required scale. The second step of the signal pre-processing is to use a moving average filter to reduce the high-frequency noise of the calibrated accelerations, and the filter is expressed as

$$Y[t] = \frac{1}{N}\sum_{i=1}^{N-1} x[t+i] \qquad (1)$$

Where $x[t]$ is the input signal, $y[t]$ is the output signal, and N is the number of points in the average filter. In this paper, we set $N = 8$. The decision of using an eight-point moving average filter is based on our empirical tests. From our experimental results, we found that the ideal value of the moving average filter to achieve the best recognition result is eight. Then, we utilize a high-pass filter to remove the gravitational acceleration from the filtered acceleration to obtain accelerations caused by hand movement. In general, the size of samples of each movement between fast and slow writers is different. Therefore, after filtering the data, we first segment each movement signal properly to extract the exact motion interval. Then, we normalize each segmented motion interval into equal sizes via interpolation. Once the pre-processing procedure is completed, the features can be extracted from the pre-processed acceleration signals.

The acceleration signals after the signal pre-processing procedure of the proposed trajectory recognition algorithm for the digit 0 are shown in Fig.3

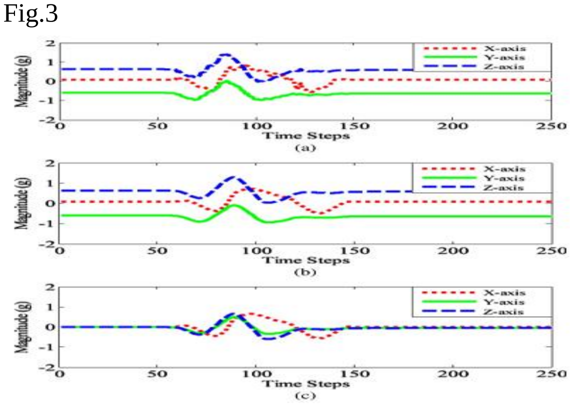

Fig.3 (a) Calibrated accelerations
(b) Filtered accelerations by a Moving average filter.(c)Filtered accelerations by a high-pass filter

The calibrated acceleration signals acquired from the pen-type accelerometer module are shown in Fig.3(a). Subsequently, the acceleration signals shown in Fig.3 (b) were filtered via the moving average filter to reduce the high-frequency noise. Finally, the gravitational acceleration as show ninFig.3(c) was removed from the filtered acceleration signals via high-pass filter to obtain the accelerations caused by hand movement.

Feature Generation

The characteristics of different hand movement signals can be obtained by extracting features from the pre-processed ***x*-, *y*-** and ***z***-axis signals, and we extract eight features from the tri-axial acceleration signals, including mean, STD, VAR, IQR correlation between axes, MAD, RMS, and energy in this study. They are explicated as follows.

Mean

The mean value of the acceleration signals of each hand motion is the dc component of the signal

$$Mean = \frac{1}{|W|}\sum_{i=1}^{|W|} x_i \quad (2)$$

Where W is the length of each hand motion.

STD

STD is the square root of VAR

$$STD = \sqrt{\frac{1}{|W|-1}\sum_{i=1}^{|W|} (x_i - m)^2} \quad (3)$$

VAR

$$VAR = \frac{1}{|W|-1}\sum_{i=1}^{|W|} (x_i - m)^2 \quad (4)$$

Where x_i is the acceleration instance and m is the mean value of x_i in (3) and (4).

IQR

When different classes have similar mean values, the inter quartile range represents the dispersion of the data and eliminates the influence of outliers in the data.

Correlation among axes

The correlation among axes is computed as the ratio of the covariance to the product of the STD for each pair of axes. For example, the correlation (*corrxy*) between two variables *x* on *x*-axis and *y* on *y*-axis is defined as

$$corr = \frac{cov(x,y)}{\sigma_x\sigma_y} = \frac{E((x-m_x)(y-m_y))}{\sigma_x\sigma_y} \quad (5)$$

Where *E* represents the expected value, σx and σy are STDs, and *mx* and *my* are the expected values of *x* and *y*, respectively. Correlation is a useful feature in discriminating motions that involve translation in only one dimension.

MAD

$$MAD = \frac{1}{|W|}\sum_{i=1}^{|W|} |x_i - m| \quad (6)$$

RMS

$$RMS = \sqrt{\frac{1}{|W|}\sum_{i=1}^{|W|} xi\ 2} \quad (7)$$

Where x_i is the acceleration instance and m is the mean value of x_i in (6) to (7).

Energy

Energy is calculated as the sum of the magnitudes of squared discrete fast Fourier transform (FFT) components of the signal in a window. The equation is defined as

$$ENERGY = \frac{1}{|W|}\sum_{i=1}^{|W|} |F_i|^2 \quad (8)$$

Where Fi is the i th FFT component of the window and $|Fi|$ is the magnitude of Fi. When the procedure of feature generation is done, 24 features are then generated. Because the amount of the extracted features is large, we adopt KBCS to select most useful features and then use LDA to reduce the dimensions of features.

C. Feature Selection

Feature selection comprises a selection criterion and a search strategy. The adopted selection criterion is the Kernel-based Class Separability (KBCS) which is originally developed by Wang[5] .

InFig.4,we can see that the IQR features of these two digits are closely overlapped. Thus, the features are not effective for classifying these two digits.

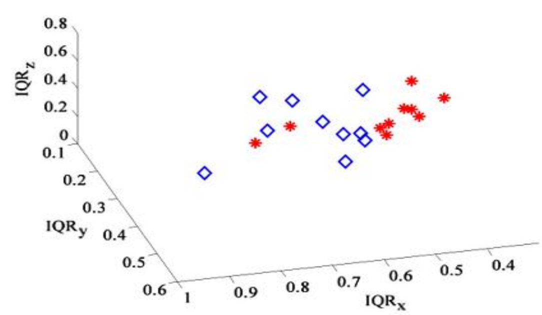

Fig.4 IQR features of (red star) digit 0 and (blue diamond) digit 6

On the contrary, the digits can be well separated by the mean features (showninFig.5) according to their vector cluster distributions.

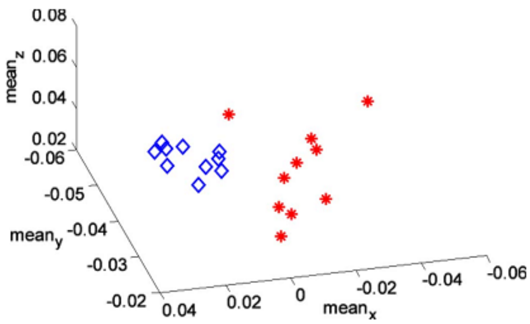

Fig.5. Mean feature of (red star) digit 0 and (blue diamond) digit 6

D. Feature Extraction

For pattern recognition problems, LDA is an effective feature extraction (or dimensionality reduction method) which uses a linear transformation to transform the original feature sets into a lower dimensional feature space. The purpose of LDA is to divide the data distribution in different classes and minimize the data distribution of the same class in a new space.

6. Conclusion

This paper has presented the innovative application of all the valuable research done in field of acceleration based trajectory recognition by the implementation of "3D drawing digital pen". The proposed device following the tracks of "Trajectory recognition algorithm" can provide some out of track and outstanding features which can enable us to write draw in the air without any physical or electronic surface. It is also about to target and reduce the technical complexity of Human-Computer Interaction.

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