

文章编号 1004-924X(2009)06-1286-07

空中手写笔笔迹检测系统

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摘要:提出了一种基于微加速度传感器与微角速度传感器的空间笔迹检测系统,并对轨迹检测系统的算法进行了描述。手写动态采集系统使用安装于手写笔上的加速度传感器和角速度传感器采集手写笔的动态信息,通过 A/D 转换将得到的数据由串行通信接口传送至计算机进行处理。该系统可用于检测手写笔在三维空间的运动轨迹,并通过三维空间的姿态角变换矩阵将手写笔动态信息投影到二维坐标平面,经过一系列积分运算最终重现笔迹信息。介绍了手写笔运动过程中重力加速度对笔迹重现的影响以及从检测到的加速度中剔除重力加速度得到纯净运动加速度的方法,对传感器的标定进行了相应的说明。实验结果表明,该系统达到了预期的效果。

关键词:笔迹检测;微加速度传感器;微角速度传感器

中图分类号:TP391.4;TH824.4 **文献标识码:**A

Handwriting detecting system for space pen

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Abstract: A handwriting detecting system based on micro-accelerometers and micro-gyros is proposed, and the algorithm of the detecting system is also described in detail. The micro-accelerometers and micro-gyros mounted on the pen are used in this dynamic handwriting acquisition system to acquire the dynamic information, and obtained data are transmitted to computer for data processing and feature analysis through a serial port after A/D conversion. The motion track of the pen in the 3-D space can be recognized through computing the matrix of attitude angles and the dynamic information of the pen is mapped on the 2-D plane. Then, the information of handwriting can be recurred on the writing plane by an integral. Finally, this paper introduces the influence of gravity acceleration on the handwriting recurrence in the movement of the pen, gives a solution to get pure movement acceleration from the gravity acceleration detected by the micro-accelerometer, and describes the sensor calibration method. Experimental results prove the designed system to be feasible.

Key words: handwriting detecting; micro-accelerometer; micro-gyro

Received date:2009-01-20;**Revised date:**2009-04-30.

Foundation item:Supported by Siemens China Research Center(Grant No. 40001014200611)

1 Introduction

The article introduces a handwriting detecting system in 3-D space, which does not need a pad below. The system is based on spatial navigation technology, which computes the dynamic information of the pen in the mapping plane through detecting the acceleration of the pen in the space relative to the writing plane. The system uses one Micro-accelerometer and two Micro-gyros as the sensor unit, through computing the attitude angles of the pen in 3-D space in real time, the linear acceleration of each axis of the pen's coordinates can be gotten, then the handwriting information on the mapping plane can also be gotten after mapping and integration^[1-2].

2 System structure

The pen system uses a single chip as the control unit, its function is to compute the attitude angles of the pen in 3-D space and the linear acceleration. The data sample unit is constituted by two uniaxial Micro-gyros ADXRS401 and one tri-axis accelerometer ADXL330, both of the two kinds of sensors are manufactured by ADI company, and there also is a 16-bit A/D converter LTC1867 which is made by Linear company. The pen system communicates with PC by RF mode, thus the track of the pen will be displayed, and a LCD can also work.

3 Track detecting algorithm

3.1 Pen system model

Fig. 1 shows the pen system model in 3-D space, the XOY plane is the writing plane, namely the plane whose info the pen mapped. The $O-xyz$ coordinates are attached to the pen, namely the coordinates of the sensor installed. To get the

track that is mapped on the writing plane, several physical variables are needed, these variables are acceleration of each axis of measurement coordinates (A_x, A_y, A_z), and the pitch angle (φ , the angle between axis OZ and XOY plane), the roll angle (θ , the angle between axis ox and XOY plane), the yaw angle (ψ , the angle between axis oy and XOY plane). Yaw angle can be ignored because of its little influence on result.

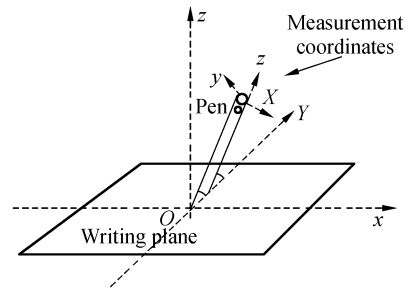


Fig. 1 System model

3.2 Algorithm introduction

The algorithm contains three parts: the measurement coordinates confirmation, the matrix of attitude angles confirmation and the solution to the pen of which the acceleration mapped on the writing plane.

The simplest instance is that the object is regarded as a point to be measured, so that the attitude changes caused by rotation can be ignored. So we only need to measure the movement characteristics on the 3 axes. Thus, the movements of this object can be expressed simply by kinematics equations. The velocity and displacement information can be gotten through computing the acceleration by following equations.

$$\begin{cases} v_* = \int_{t_0}^{t_e} a_* dt + v_0 \\ s_* = \int_{t_0}^{t_e} v_* dt + s_0 \end{cases}, \quad (1)$$

'*' is on behalf of any axis among X, Y, Z of the absolute coordinates, v_0 and s_0 represent original velocity and displacement respectively, t_0 is the

start time of measurement, t_e is the stop time of measurement. So we only need to measure the acceleration of 3 axes, the start time and the stop time to get the velocity and displacement characteristics on the 3 axes. The pen cannot be seen as a point, because of its shape, shown as Fig. 1. Firstly, the pen's coordinates need to be confirmed. Suppose g_x, g_y, g_z on behalf of the weights of gravitational acceleration on 3 axes of pen's coordinates. Because the changes of yaw angle have a little influence on the accelerometer when the pen moves horizontally or vertically,

$$\begin{pmatrix} a_x \\ a_y \\ a_z \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \sin \theta & -\cos \theta \\ 0 & \cos \theta & \sin \theta \end{pmatrix} \begin{pmatrix} \cos \varphi & -\sin \varphi & 0 \\ \sin \varphi & \cos \varphi & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos \psi & 0 & -\sin \psi \\ 0 & 1 & 0 \\ \sin \psi & 0 & \cos \psi \end{pmatrix} \begin{pmatrix} a_x \\ a_y \\ a_z \end{pmatrix}, \quad (3)$$

Thereinto the equation (3), $\theta = \theta_0 + \theta', \phi = \phi_0 + \phi', \psi = \psi_0 + \psi', \theta', \phi', \psi'$ are on behalf of the dynamic angle changes which are sampled by micro-gyros during the writing action^[3].

Original attitude angle determines the beginning situation of writing plane, the angles be-

$$\begin{pmatrix} a_x \\ a_y \\ a_z \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \sin \theta & -\cos \theta \\ 0 & \cos \theta & \sin \theta \end{pmatrix} \begin{pmatrix} \cos \varphi & -\sin \varphi & 0 \\ \sin \varphi & \cos \varphi & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} a_x \\ a_y \\ a_z \end{pmatrix}, \quad (4)$$

Through the equation (4), the three weights of gravitational acceleration mapped on writing plane can be gotten by the same way. As shown in equation (5), A_* is the linear acceleration of each axis of writing plane's coordinates, a_* represents the actual output acceleration of each axis of pen's coordinates, g_* is the mapping gravitational acceleration value of writing plane's coordinates^[5].

$$A_* = a_* - g_*, \quad (5)$$

The basic equations to compute the velocity and displacement are shown in the following equations^[6]:

the system can be simplified as yaw angle equal to zero. The pitch angle φ and roll angle θ between pen's coordinates and writing pen's coordinates can be gotten in the following equations. In this system writing plane's coordinates superpose with geographical coordinates.

$$\begin{cases} \varphi = \arcsin(g_x/g) \\ \theta = \arcsin(g_y/g) \end{cases}. \quad (2)$$

The relationship of acceleration mapped on writing plane from pen's coordinates are expressed by equations:

tween writing plane and geographical coordinates are pitch ϕ_0 , roll θ_0 , and yaw ψ_0 . Because the yaw angle varies little during the pen's movement, the yaw angle is regarded as a constant, namely $\psi' \approx 0$, the above equations can be simplified as^[4]:

$$\begin{cases} v_* = \int_{t_0}^{t_e} A_* dt + v_0 \\ s_* = \int_{t_0}^{t_e} v_* dt + s_0 \end{cases}, \quad (6)$$

"*" is on behalf of any direction among X, Y, Z.

After sampling the acceleration signal becomes discrete signal, so the accumulative total will replace the integral. Suppose the weights of acceleration on mapping plane (writing plane) are shown as follows:

$$a_{0i} = (a_{0ix}, a_{0iy}, a_{0iz})^T.$$

Sampling interval is Δt , $\Delta T = 5\Delta t$, suppose displacement variable $S = (S_x, S_y, S_z)$, then the following equations can be gotten.

$$\begin{cases} S_x = \sum_{j=u}^{u+4} \left(\sum_{i=k}^{k+4} a_{0,x}(i+j)\Delta t \right) \Delta T \\ S_y = \sum_{j=u}^{u+4} \left(\sum_{i=k}^{k+4} a_{0,y}(i+j)\Delta t \right) \Delta T \end{cases}, \quad (7)$$

$$(k = 1, 2, 3, 4, \dots, n; u = 0, 1, 2, 3, \dots, n-4).$$

Recurrence formulas of displacement can be gotten from equation (7) are shown as follows:

$$\begin{cases} S_{x(i+1)} = S_{xi} - \left(\sum_{k=i}^{i+4} a_{0,xk} \Delta t \right) \Delta T + \left(\sum_{k=i+5}^{i+9} a_{0,xk} \Delta t \right) \Delta T \\ S_{y(i+1)} = S_{yi} - \left(\sum_{k=i}^{i+4} a_{0,yk} \Delta t \right) \Delta T + \left(\sum_{k=i+5}^{i+9} a_{0,yk} \Delta t \right) \Delta T \end{cases}, \quad (8)$$

Thereinto the equation (8)

$$S_1 = \sum_{j=0}^4 \left(\sum_{i=1}^5 a_0(i+j)\Delta t \right) \Delta T.$$

4 Sensor calibration

4.1 Micro-gyro rate test model

In this system gyro is used for real-time to detect the change of initial state attitude angle. It is very important for eliminating the gravity acceleration components, so the gyro calibration is also very important. The following is the gyro rate test model^[7],

Take ADXRS401 micro-gyro for example:

$$U = K_0 + K_1 \times \omega, \quad (9)$$

U —Output voltage of micro-gyro, unit is V;

K_0 —Drift value of micro-gyro, unit is V;

K_1 —Scale factor of micro-gyro, unit is V / ((°)/s);

ω —Angular velocity input of micro-gyro, unit is °/s.

4.2 Micro-gyro calibration test

(1) Put the micro-gyro in the test equipment and fix the sensor on the turntable. The equipment we used is DTOP300E type uniaxial turntable.

(2) Give micro-gyro power supply of 5 V.

(3) Give angular velocity in $\pm 10^\circ/\text{s}$, $\pm 20^\circ/\text{s}$, $\pm 30^\circ/\text{s}$, $\pm 40^\circ/\text{s}$, $\pm 50^\circ/\text{s}$, $\pm 60^\circ/\text{s}$, $\pm 70^\circ/\text{s}$ through the turntable computer.

(4) After the turntable rotated at least four

rounds by one angular velocity we began to sample and have sampled continuously for one minute, then recorded one groups of data, finally we got 15 group data, shown in Tab. 1.

Tab. 1 Micro-gyro calibration data

angular velocity	gyro I output	gyro II output
(°/s)	(V)	(V)
70	3.265	3.594
60	3.125	3.441
50	2.988	3.291
40	2.849	3.132
30	2.702	2.981
20	2.558	2.832
10	2.419	2.670
0	2.290	2.520
-10	2.150	2.330
-20	2.010	2.209
-30	1.870	2.061
-40	1.731	1.914
-50	1.593	1.757
-60	1.455	1.602
-70	1.317	1.451

Through Matlab data fitting we got:

Gyro I : $K_0 = 2.290, K_1 = 0.0139$ namely: $V = 2.290 + 0.0139\omega$

Gyro II : $K_0 = 2.520, K_1 = 0.0153$ namely: $V = 2.520 + 0.0153\omega$

4.3 Micro-accelerometer calibration test

The micro-accelerometer is used to test the attitude angles when the pen hasn't yet written, in other word it's used to test the static attitude angles. Due to the acceleration sensor adopted for integrated triaxial acceleration sensor, so the orthogonal error will not affect the precision. The most error sources are zero errors, sensitivity errors and the errors caused by a A/D conversion. We select $\pm g$ and 0 as the special points to calibrate the sensor's zero output and sensitivity^[7]. The Tab. 2 shows calibration results of each axis of X, Y, Z. The ADC is 16 bit and reference voltage is 4.096 V.

Tab. 2 Micro-accelerometer calibration data

X axis (V)							mean
0	1.501	1.498	1.496	1.505	1.495	1.499	
+g	1.795	1.793	1.790	1.798	1.791	1.793	
-g	1.205	1.203	1.200	1.211	1.202	1.204	
S	0.295 V/g						
Y axis (V)							mean
0	1.524	1.520	1.522	1.518	1.525	1.522	
+g	1.823	1.820	1.818	1.820	1.824	1.821	
-g	1.225	1.220	1.222	1.220	1.224	1.222	
S	0.299 V/g						
Z axis (V)							mean
0	1.504	1.505	1.508	1.503	1.505	1.505	
+g	1.807	1.805	1.811	1.812	1.801	1.807	
-g	1.203	1.203	1.201	1.208	1.205	1.204	
S	0.302 V/g						

5 System test result analysis

In the system test process we tested the round track and analyzed the dynamic characters of this track that is representative. The dynamic curves are shown in the following figures. Axis z of accelerometer is perpendicular to the mapping plane due to the sensor installation, so the axis z has no effect on the track recurrence. To recur the writing track, the acceleration of axis x and axis y of accelerometer are both needed. Fig. 2, 3, 4 are the curves of acceleration, velocity and displacement of the round track. Fig. 5 is the track curve.

Other track identified pictures are shown in Fig. 6 and Fig. 7:

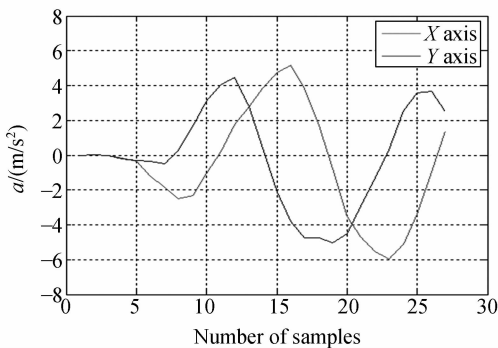


Fig. 2 Acceleration curve

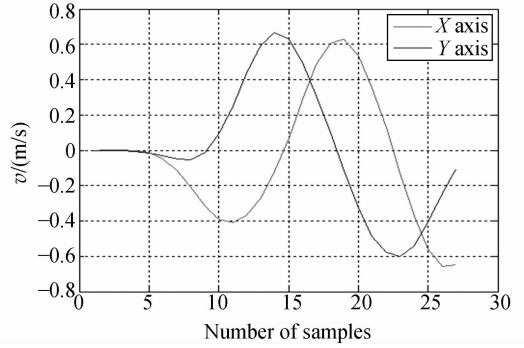


Fig. 3 Velocity curve

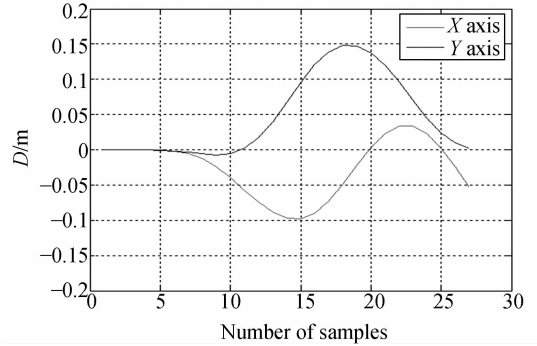


Fig. 4 Displacement curve

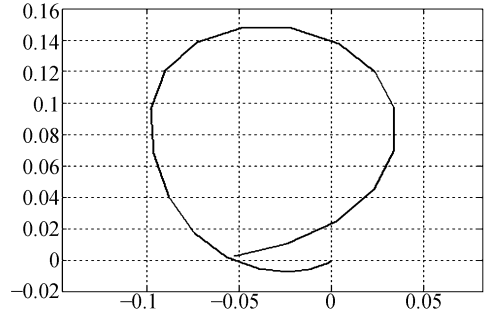


Fig. 5 Track curve

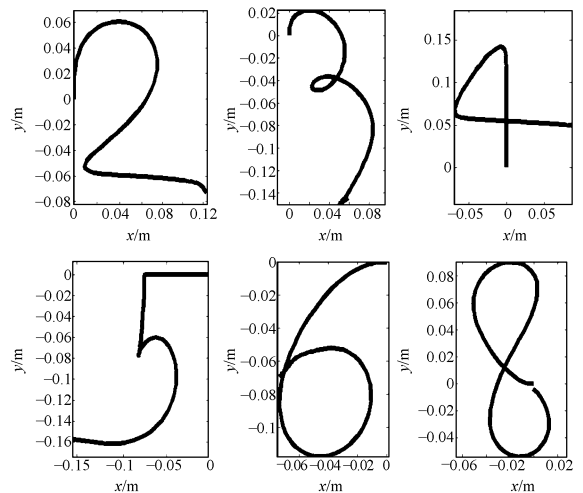


Fig. 6 Number track

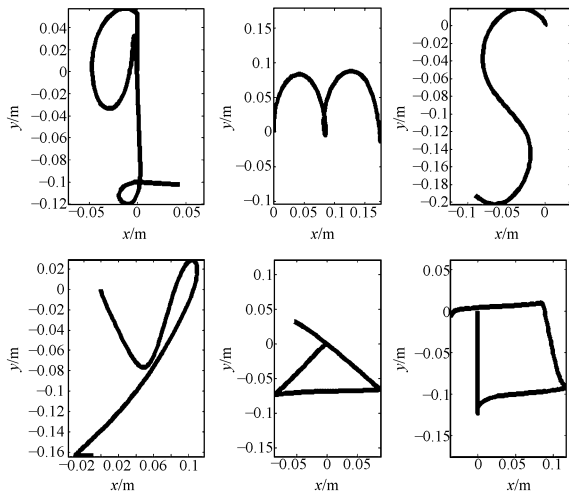


Fig. 7 Letter and symbol tracks

6 Conclusions

In this paper, a kind of handwriting detec-

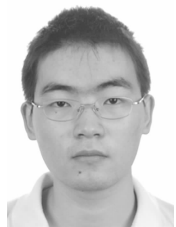
ting system based on MEMS inertia sensors is introduced. The system samples the pen's acceleration and attitude angle changes, then computes the movement track of the pen, finally the recurrence of handwriting is finished. The test result validates correctness of the theory. The system is different from usual 2-D electronic pen systems, its greatest strength is freely writing in 3-D space and this is the first case that the inertial navigation theory is used for a pen.

The next tasks will be to content the sensor data fusion and accumulation error analysis of the double integral. Then the more accurate track can be gotten. In addition, a better algorithm for the gravitational acceleration removal is needed to look for in order to get more purely dynamic acceleration.

References:

- [1] LAM A H F, LI W J. MIDS: GUI and TUI in mid2 air using MEMS Sensors[C]. *IEEE/RSJ International Conference*, 2002(2):1184 -1189.
- [2] HUMPHREYS D. *An Input Device for the Control of 3D Graphics* [R]. Birmingham: Final Report of University of Birmingham, 2003.
- [3] ZHANG SH X, LI J. *Strapdown Inertial Navigation System* [M]. Beijing: Defense Industry Press, 1992. (in Chinese)
- [4] ZHANG R H, JIA H G, CHEN T, *et al.*. Attitude solution of strapdown inertial navigation system based on the method of quaternions[J]. *Opt. Precision Eng.*, 2008, 30(10): 1963-1971. (in Chinese)
- [5] HOU X F, LIU R, ZHOU ZH R. Application of Accelerometer MMA7260 for Abstraction of Walking Character [J]. *Chinese Journal of Sensors and Actuators*, 2007, 20(3): 507-511. (in Chinese)
- [6] ZHU R, ZHOU ZH Y. An Attitude Measurement System Based on MEMS [J]. *Measurement and Control Technology*, 2002, 21(10): 6-8. (in Chinese)
- [7] DU H L, ZHANG R H, LI P, *et al.*. The attitude solution modules of strapdown inertial navigation system[J]. *Opt. Precision Eng.*, 2008, 16(10): 1956-1963. (in Chinese)

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●下期预告

双散射角光学粒子计数器的研制

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为了实现同时测量气溶胶粒子的谱分布和折射率,研制了双角度光学粒子计数器(D-OPC),采用 60° 和 110° 双散射角系统对气溶胶谱分布进行测量。首先,利用Mie散射理论定义敏感函数,选取两个最佳的散射角,使这两个散射角既对折射率敏感又不线性相关。然后,利用气溶胶折射率对两散射角系统敏感性差异来反演气溶胶折射率。最后,利用该仪器对大气气溶胶谱分布以及折射率进行实际测量。与TSI公司黑炭仪和浊度计测量的吸收系数和散射系数对比表明:双散射角光学粒子计数器测量气溶胶折射率和谱分布结果合理,测量误差 $<20\%$ 。该仪器可以满足同时测量气溶胶粒子谱分布和折射率的需要。