# 筆跡入力用新規デバイスの開発

## Novel Device for Inputting Handwriting Trajectory

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要　　旨

図形や記号，文字をコンピュータへ入力するためのペン型入力装置を開発した．ペンに内蔵した複数の慣性力検出センサにより筆記面上での2次元の筆記軌跡を再現する．センサとしては3個の加速度センサと3個のジャイロを用いた．ペン上の各軸方向の加速度と各軸周りの角速度が検出でき，これら6自由度の物理量よりペン先の筆記軌跡を計算できる．問題となる積分誤差は，速度の次元で補正処理するアルゴリズムで低減できることを見出した．実際のシステムを作製し，評価することで筆記入力装置としての可能性を示すことができた．

**ABSTRACT**

A pen-shaped input apparatus for inputting drawings, symbols, characters into a data processing device, such as a computer, is developed. It is able to trace a handwritten two-dimensional trajectory using built-in inertial sensors. As the sensor, it has three accelerometers and three gyroscopes. By detecting accelerations about three axes and angular rates around them as six degrees of freedom, it can represent the two-dimensional trajectory of the pen tip after additional calculation. A velocity correction method enables precise trajectories to be represented with a small integration error. Experimental results demonstrate the feasibility of this device as a handwritten input apparatus.

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# 1. Introduction

There are 2 applications of a handwriting input apparatus for a computer. One is signature verification for security purposes[1) 2)] and character recognition for a PDA (Personal Digital Assistant). The other is to input the written trajectory itself. In the former, it is not necessary to represent the trajectory; it can be verified or recognized directly by sensing the pen motion data, for example.[3)] The latter application is used to input the actual trajectory of written drawings, symbols, and characters. Here, we call this kind of appliance, which retains the written trajectory as digital data, "Digital Ink".

A tablet that has a sensor to detect the trajectory of a pen tip has been widely applied as a "Digital Ink" appliance for personal computers (PCs). As its method can detect the pen tip position directly, the handwritten trajectory is represented with high and reliable accuracy. However, the tablet is large, so it is difficult to apply to mobile or office applications where the workspace is limited.

What is needed is to shrink the sensing device and peripheral circuits. Our target is mobile and office applications based on new small "Digital Ink" appliances. The future scenario of our "Digital Ink" appliance is shown in Fig.1. Writing tools are connected to various networked instruments (public telephone, office telephone, cellular phone, and PC) and send/receive data to/from each other.

Recently, there have been several studies related to systems of this kind in some research organizations and venture companies. There are two main approaches to shrinking "Digital Ink" appliances: i) using inertial sensors to detect acceleration, angular rate, tilting, and so on and ii) detecting the distance between the pen tip and a reference point by sending and receiving ultrasonic waves or infrared rays, and calculating the pen tip position by triangulation. And the apparatus for inputting the written trajectory is researched, which is to detect three accelerations and three angular rates with six degrees of freedom (6DOF).[4)] This method based on INS (Inertial Navigation System) of the navigation system for an aircraft and an automobile. And another apparatus for inputting the written trajectory by means of accelerometers is studied, too.[5-7)] However the gravity influence can't be eliminated completely in these researches, therefore it is difficult to represent the precise trajectory.

We chose to study the first approach using such a inertial sensors. This system needs nothing more than the pen itself, so it is the ultimate small appliance. If inertial sensors can detect the writing motion with 6DOF, then the two-dimensional writing trajectory can be represented after some calculation of coordinate transformation and double integration.[8)] Here we think that the calculating method how eliminates the integration error is much worth researching.

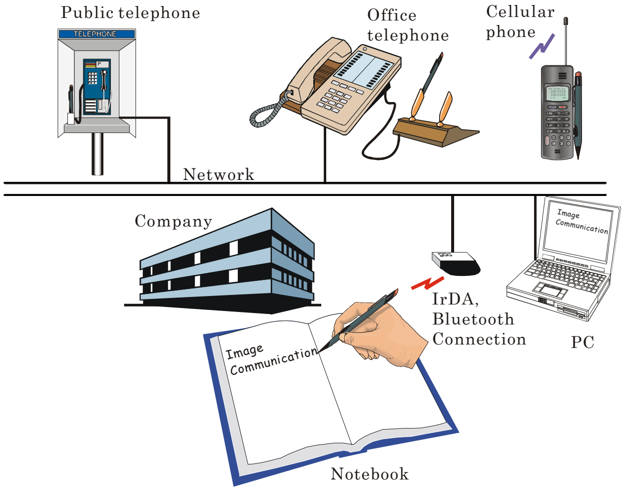


Fig.1 Future application using our "Digital Ink" appliance.

# 2. Detection of Pen Motion in Handwriting

## 2-1 Frequency of Ordinary Handwriting

The FFT (Fast Fourier Transformation) power spectrum of handwriting acceleration on paper with a ball-point pen is shown in Fig.2. Its profile consists of two frequency levels. The lower one below 10 Hz is the genuine motion signal, while the higher one above 100 Hz corresponds to the interaction between the pen tip and paper surface[5) 9)]. These signals can easily be separated by ordinary filtering. The extracted higher one is available to correct some error.

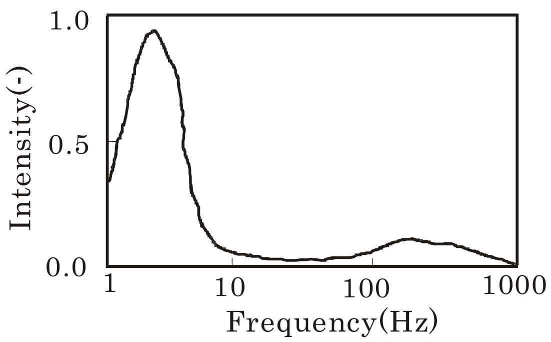


Fig.2 Power spectrum of handwriting acceleration.

## 2-2 Sensing Devices

The sensing devices consist of three accelerometers, three gyroscopes, and a pen touch switch. The layout of each sensor except the pen touch switch and coordinate systems are shown in Fig.3. A pair of accelerometers set at a distance $L_1$ from the pen tip detects the Xs- and Ys-axis accelerations and another accelerometer set at a distance $L_2$ from the pen tip detects the Zs-axis acceleration . The actual values of $L_1$ and $L_2$ in our prototype are 41 and 160 mm, respectively. There are also three gyroscopes set along the Xs, Ys, and Zs axes approximately at the center of the pen. The specifications of these sensors are shown in Table 1.

Table 1 Sensor specifications

| | Accelerometer | Gyroscope |
|---|---|---|
| Maker | IC Sensors, Inc. | Tokin Cooperation |
| Principle | Piezoresistive | Piezoelectric |
| Model | 3021-002P | CG-16D |
| Sensitivity ※ | 1.53 mV/(m/s2) | 1.1 mV/(deg./s) |

※ typical value

The accelerometers are fabricated by MEMS (Micro Electrical Mechatronics Systems) technology, so they will become smaller and smaller during the next few years. The gyroscope was developed for an image stabilizer in consumer cameras and binoculars.

Currently, the gyroscope is rather large to fit into a pen-like device, but a lot of research and development of micro-fabrication techniques[10] for gyroscopes is in progress and there are many desirable applications, so we can expect smaller ones soon.

## 2-3 Definition of Coordinate Systems

Two coordinate systems are defined, as shown in Fig.3. The Laboratory frame is the coordinate system ($X_G$, $Y_G$, $Z_G$), where the $Z_G$ axis corresponds to the direction in which gravity is acting. The Pen frame is the coordinate system ($X_S$, $Y_S$, $Z_S$), where the $Z_S$ axis corresponds to the axis of the pen core.

Rotation vector is also defined to denote the rotation of the Pen frame relative to the Laboratory frame.

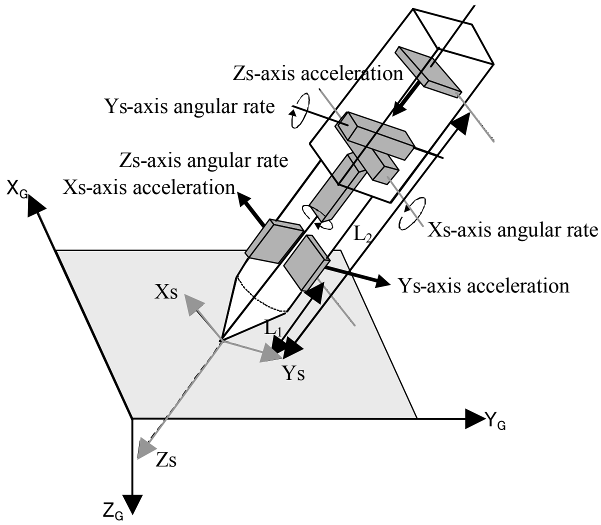


Fig.3 Sensor layout and coordinate systems.

# 3. Algorithm for Calculating Pen Tip Trajectory

The fundamental working process of the system is shown in Fig.5. It mainly consists of seven processes that are described below in 3.1. to 3.7.

## 3-1 Filtering

First, both the acceleration and angular rate signals pass through the filtering stage. The acceleration signals pass through both a high pass filter (HPF) and a low pass filter (LPF); the angular rate signals pass through only an LPF. These filters may be either hardware with electrical circuits or software using digital filtering.

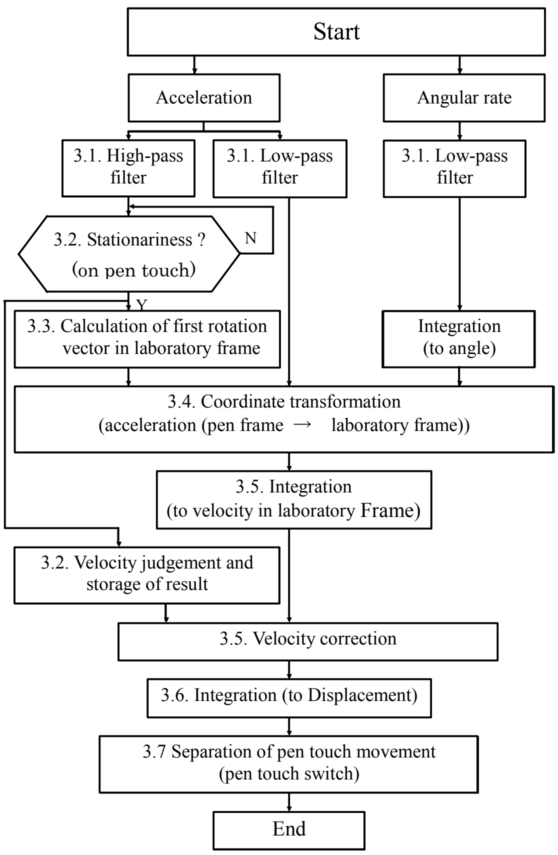


Fig.4 Fundamental working process of the system.

## 3-2 Velocity Judgement

The velocity judgement using HPF acceleration signal is shown in Fig.4. The pen is judged to be stationary when the acceleration falls below a threshold level. This knowledge is effective for correcting the integration error that occurs in velocity. The number of stationary points in writing a character is used in the later integration sequence, so the result is stored.

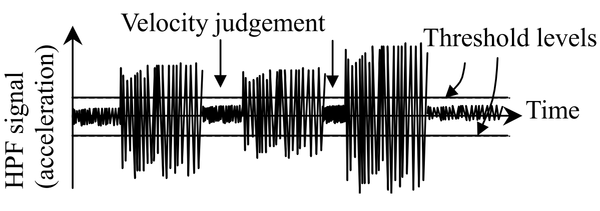


Fig.5 Velocity judgement using HPF acceleration signal.

## 3-3 First Rotation Vector

Now the rotation vector is defined as the vector that Pen frame is rotating to Laboratory frame to the direction of rotating axis of $\phi_0$. The relationship between each coordinate system is shown in Fig.6.

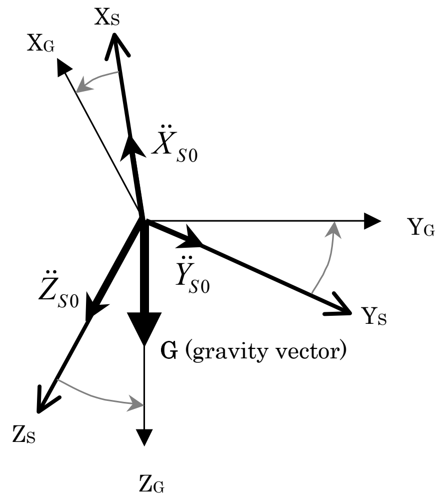


Fig.6 The relationship between each coordinate system.

The gravity signal detected by accelerometers gives the absolute rotation vector value $\phi_0$. This value is calculated when the pen tip is stationary. The value of $e_{X0}, e_{Y0}$ shows the unit vector of each axis.

Here it is assuming that the direction of normal line on a paper is corresponding to gravity direction. The small subscripts "0" mean initial value of each.

$$\phi_0 = \begin{bmatrix} \phi_0 e_{X0} \\ \phi_0 e_{Y0} \\ 0 \end{bmatrix} \qquad (1)$$

Here $\phi_0, e_{X0}, e_{Y0}$ are given by

$$\phi_0 = \frac{1}{2}\cos^{-1}\left( \frac{\ddot{Z}_{S0} - \left(\ddot{X}_{S0}{}^2 + \ddot{Y}_{S0}{}^2\right)}{\ddot{X}_{S0}{}^2 + \ddot{Y}_{S0}{}^2 + \ddot{Z}_{S0}{}^2} \right) \qquad (1\text{-a})$$

$$e_{X0} = \frac{-\ddot{Y}_{S0}}{\sqrt{\ddot{X}_{S0}{}^2 + \ddot{Y}_{S0}{}^2}} \qquad (1\text{-b})$$

$$e_{Y0} = \frac{-\ddot{X}_{S0}}{\sqrt{\ddot{X}_{S0}^{\,2} + \ddot{Y}_{S0}^{\,2}}} \quad \cdots\cdots\cdots\cdots\cdots \text{(1-c)}$$

## 3-4 Coordinate Transformation

Using the LPF acceleration signals, the velocity judgement result, and the integration value (angle) of angular rate, the accelerations in the Pen frame are transformed into ones in the Laboratory frame. This calculation also corrects the positions of the built-in accelerometers.

(a) Calculating the Rotation Vector $\phi(\phi_X, \phi_Y, \phi_Z)\phi$

$$\phi_n = \phi_{n-1} + \left(\omega_S + \frac{1}{2}\phi_{n-1} \times \omega_S\right) \Delta t \quad \cdots\cdots\cdots \text{(2)}$$

$\phi_n$ : Rotation vector on "n" sample

$\phi_{n-1}$ : Rotation vector on "n-1" sample

$\omega_s$ : Angular rate vector $(\omega_{XS}, \omega_{YS}, \omega_{ZS})$

$\Delta t$ : Sampling time

(b) Calculating the Eulerian Parameter $(\chi, \rho_X, \rho_Y, \rho_Z)$

$$\chi = \cos\frac{\phi}{2} \quad \cdots\cdots\cdots\cdots\cdots \text{(3-a)}$$

$$\rho_X = \frac{\phi_X}{\phi}\left(\sin\frac{\phi}{2}\right), \rho_Y = \frac{\phi_Y}{\phi}\left(\sin\frac{\phi}{2}\right), \rho_Z = \frac{\phi_Z}{\phi}\left(\sin\frac{\phi}{2}\right) \quad \cdots\cdots \text{(3-b)}$$

$$\phi = |\phi| \quad \cdots\cdots\cdots\cdots\cdots \text{(3-c)}$$

(c) Calculating the Coordinate Transformation Matrix $C_G^S$

$$= \begin{bmatrix} \chi^2 + \rho_X^2 - \rho_Y^2 - \rho_Z^2 & 2(\rho_X\rho_Y - \chi\rho_Z) & 2(\rho_X\rho_Z + \chi\rho_Y) \\ 2(\rho_X\rho_Y + \chi\rho_Z) & \chi^2 - \rho_X^2 + \rho_Y^2 - \rho_Z^2 & 2(\rho_Y\rho_Z - \chi\rho_X) \\ 2(\rho_X\rho_Z - \chi\rho_Y) & 2(\rho_Y\rho_Z + \chi\rho_X) & \chi^2 - \rho_X^2 - \rho_Y^2 + \rho_Z^2 \end{bmatrix}$$

$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \text{(4)}$$

: Coordinate transformation matrix from Pen frame to Laboratory frame

(d) Coordinate Transformation

The pen tip acceleration $(\ddot{X}0_G, \ddot{Y}0_G, \ddot{Z}0_G)$ in the Laboratory frame can be acquired as

$$\begin{bmatrix} \ddot{X}_{oG} \\ \ddot{Y}_{oG} \\ \ddot{Z}_{oG} \end{bmatrix} = C_G^S \left( \begin{bmatrix} \ddot{X}_S \\ \ddot{Y}_S \\ \ddot{Z}_S \end{bmatrix} - \begin{bmatrix} -\dot{\omega}_{yS} L_1 \\ \dot{\omega}_{xS} L_1 \\ 0 \end{bmatrix} - \begin{bmatrix} -\omega_{zS}\omega_{xS} L_1 \\ -\omega_{yS}\omega_{zS} L_1 \\ (\omega_{xS}^{\,2} + \omega_{yS}^{\,2}) L_2 \end{bmatrix} \right) + \begin{bmatrix} 0 \\ 0 \\ g \end{bmatrix}$$

$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \text{(5)}$$

Here $(\ddot{X}_S, \ddot{Y}_S, \ddot{Z}_S)$ is the detected acceleration, $(\omega_{XS}, \omega_{YS}, \omega_{Zs})$ and $(\omega_{XS}, \omega_{YS})$ are the detected angular rate and calculated angular acceleration of each, and "g" is the acceleration of gravity (9.81 m/s$^2$).

## 3-5 Integration to Velocity and Velocity Correction

The accelerations in the Laboratory frame are integrated to give a velocity. However, their values include a lot of integration error caused by sensor signal noise and drift. To reduce the integration error, we correct the velocity by utilizing the velocity judgement result. This can prevent the divergence of integration.

## 3-6 Integration to Displacement

A simple integration such as Simpson's law is performed on the velocity values. This can yield an accurate displacement value with small divergence.

## 3-7 Distinguishing Pen Touch Movement

Distinguishing whether the pen is touched or untouched enables complicated multi-stroke data to be represented.

# 4. Correction Method to Achieve Accurate Trajectory Representation

Detection of the pen tip stationary point and velocity correction is effective to achieve accurate trajectory representation. And particulars about these processes are described below.

### 4-1 Pen Tip Stationary Points on Handwriting

Our analysis of high-frequency acceleration in natural handwriting (Table 2) showed that it occurs quite often when the pen tip velocity becomes almost zero. The average number of stationary points is almost more than three points, so this information can be used for corrections of integration error.

Table 2 Average stationary points. (total 1145 characters written by one person)

| Character type | Average number of stationary points |
|---|---|
| Letters | 4.1 |
| Numerals | 3.4 |
| Kanji (Japanese) | 12.5 |
| Hiragana (Japanese) | 5.1 |
| Katakana (Japanese) | 4.8 |

### 4-2 Velocity Correction

The data for processing are shown in Fig.7. The HPF signal (a) shows when the velocity becomes zero in A, B, C. The uncorrected velocity data (b) leads to a bigger and bigger error as the integration error diverges. Correction using the gradient among zero-velocity points (a, b and b, c) brings the experimental velocity closer to the reference.

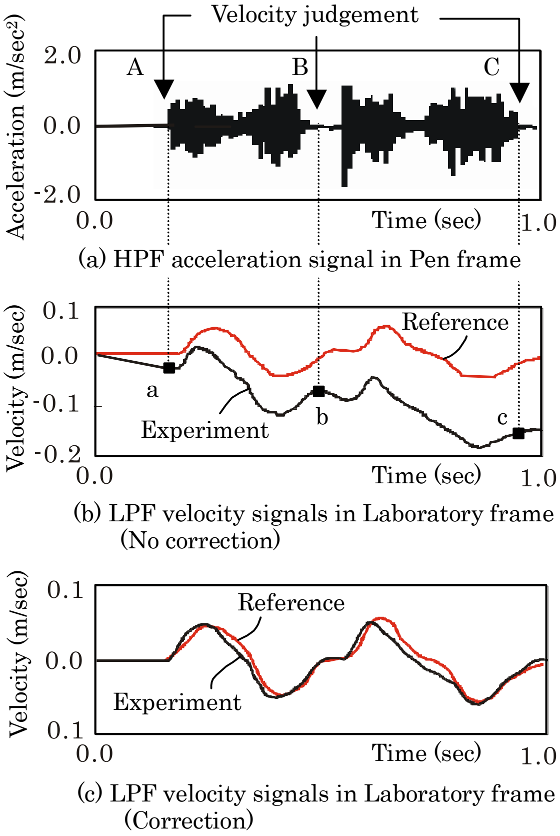


Fig.7 Velocity judgement and correction.

## 5. Prototype and Experiments

### 5-1 Prototype Unit

Our prototype unit is shown in Fig.8. It consists of sensors and their analog electrical circuits. An amplifier is provided for differential amplification of the accelerometers. Circuits for adjusting the offset voltage value and amplifying the voltage are provided for the gyroscopes. There is an interface for connecting external appliances by wiring, but in future a wireless interface and memory will be provided for practical use.

What is designing smart layout of each sensor can make it small as usual pen.

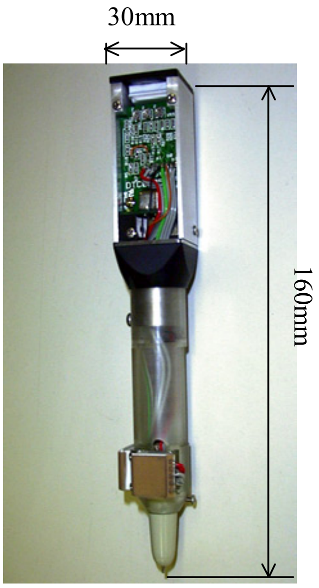


Fig.8　Prototype unit.

## 5-2　Experimental System

The experimental system is schematically shown in Fig.9. An electromagnetic tablet was used to acquire the ideal true writing trajectory. The tablet was connected to an RS232C serial interface on a PC. The analog output signals of the prototype unit were input to an ordinary I/O board having a 12-bit A/D converter. Almost simultaneous sampling between the tablet and prototype was achieved, so the representation result is a quantitative evaluation.

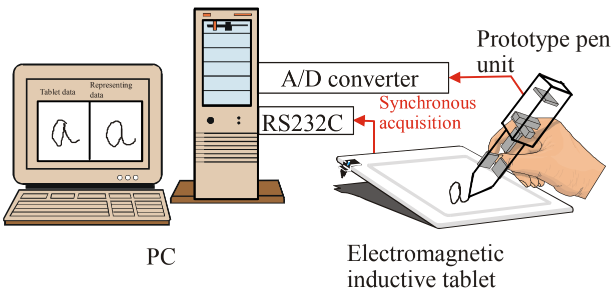


Fig.9　Experimental system to evaluate the represented trajectory.

## 5-3　Experimental Results

Typical results for trajectories of Japanese writing are shown in Figs. 10 and 11. Fig.10(a) shows the tablet data for reference and (b) shows the representation data obtained by our prototype. The written characters were each about 10 mm square. The bold points in the figures indicate the stationary points used for recognition. Some of the stationary points used by the prototype unit differed from those used by the tablet.

These results demonstrate the effectiveness of our prototype system.

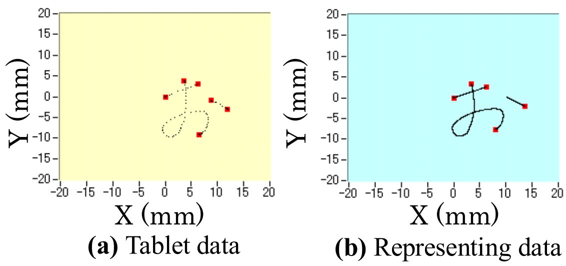


Fig.10 Handwriting trajectory (1).

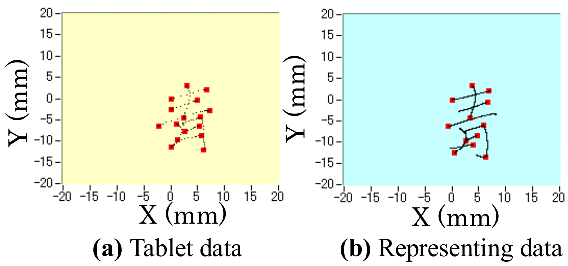


Fig.11 Handwriting trajectory (2).

# 6. Conclusion

Our 6DOF prototype handwriting input apparatus can detect accelerations and angular rates around three axes. By using a velocity correction method to calculate the accurate pen tip trajectory, we obtained several good representation results, demonstrating its feasibility.

A future goal is to be making practicable system as described in our future scenario.


### Reference)

1) Dominiek Reynaerts, et al. : Design of an Advanced Computer Writing Tool, International on Micro Machine and Human Science, IEEE, Sixth, (1995) pp. 229-234.

2) Dirk Diddens, et al. : Design of a ring-shaped three-axis micro force/torque sensor, Sensors and Actuators, A 46-47, (1995) pp. 225-232.

3) Furuta, et al. : A Study of Character Recognition by Detecting Pen Motion, PROCEEDINGS OF THE 1997 ENGINEERING SOCIETY CONFERENCE OF IECE, (1997) pp. 190.

4) Christopher Verplaetse : Can A Pen Remember What It Has Written Using Inertial Navigation? : An Evaluation Of Current Accelerometer Technology, http://xenia.media.mit.edu/~verp/projects/smartpen/, (1995)

5) Ishikawa, et al. : Extraction of Character Information from Acceleration of Handwriting Pen, THE TRANSACTIONS OF THE INSTITUTE OF ELECTRONICS, INFORMATION AND COMMUNICATION ENGINEERS, VOL.J76-D-Ⅰ No.10, (1993) pp. 541-543.

6) Ishikawa, et al. :Reproduction of character pattern from pen acceleration in handwriting, Proceedings of the 24th Joint Conference on Imaging Technology, (1993) pp. 25-28.

7) Miyagawa, et al. : Character Pattern Reproduction from Handwriting Pen Acceleration, THE TRANSACTIONS OF THE INSTITUTE OF ELECTRONICS, INFORMATION AND COMMUNICATION ENGINEERS, VOL. J83-D-Ⅱ No.2, (2000) pp. 671-679.

8) Sato et al. : A PEN-SHAPED INPUT APPARATUS, US. Patent, (1999)USRP.5902968

9) Sato et al. : A Study of Handwriting Input Apparatus by Inertial Sensing, 2000 JSME Conference on Robotics and Mechatronics (ROBOMEC'00), (2000)1P1-02-002

10) S.Sassen et al. : Tuning fork silicon angular rate sensor with enhanced performance for automotive applications, Sensors and Actuators A 83, (2000) pp.80-83.