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MEMS based 3D Digital Writing Device using Micro Inertial Measurement Unit (µIMU)

L.Megala[1], B.Devanathan[2]

Assistant Professor, Department of ECE, V.R.S. College of Engineering & Technology, Arasur, Villupuram, Tamilnadu, India [1]

Lecturer, Department of ECE, University College of Engineering, Kakuppam, Villupuram, India [2]

Abstract: In this automation era, many handwritten documents are digitized for ease of backup and transmission. The demands for digital writing instruments are thus expected to grow rapidly incoming years. There are many different types of systems already available on the market. Recently, we have developed a prototype of a MEMS (Micro-Electro-Mechanical Systems) based 3D digital writing instrument which makes use of a micro inertial measurement unit (µIMU) constructed from MEMS accelerometers and gyroscopes for real-time capture of handwriting. This idea has been proposed forever 10 years however; to date there is still no successful product on the market. One reason is that the necessary double integration from acceleration to position propagates the noise associated with the sensors to the tracked position, and such errors increase without bound. In this paper, a study of the sources of errors in µIMU, accelerometers are given. Different existing error reduction techniques are investigated and novel schemes proposed with an aim to provide a practical solution to this problem.

Keywords: MEMS, accelerometers, gyroscopes, integration, 3D.

I. Introduction

The " Electronic Whiteboard" and " Digital Pen" are new paradigms in the automation industry that may someday completely replace the computer keyboard, which is still the preferred alphanumeric human – to-computer input device. These new devices aim to capture human handwriting or drawing motions in real-time and store motion strokes for character recognition or information retrieval at a later time. In 1964, the first graphics tablets was launched, the RAND Tablet, also known as the grafacon (Graphic Converter).

It makes use of electro magnetic resonance to digitize pen motion. In the next 40 years of development, many different well developed methodologies to digitize hand writing have been proposed Targeting business and academic institutions, ultrasonic, infrared and optical sensing are currently the most popular technologies for detecting the position of a digital pen on a large area electronic white board. These systems allow users to write on specific surfaces with restricted active areas by the usage of special dry-erase pens.

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 techniques have become an indispensable component in our daily life. Recently, an attractive alternative, a portable device embedded with inertial sensors, has been proposed to sense the activities of human and to capture motion trajectory information from accelerations for recognizing gestures or handwriting of inertia sensors for general motion sensing is that they can be operated without any external reference and limitation in working conditions. However, motion trajectory recognition is relatively complicated because different users have different speeds and styles to generate various motion trajectories. Thus, many researchers have tried to narrow down the problem domain for increasing the accuracy of handwriting recognition systems. Uses optical detection techniques. A specialized pen emits a light wave that is deflected by patterns built onto specialized digital paper. By detecting the reflected light, the pen can be made to record its position on the paper. All existing products, including eBeam, mimeo, Logitech, io T M 2 and Nokia SU- 1B, require special writing surfaces or attachments to function and the active area for position detection is limited.


Fig. 1: a) Digital pen b) Digital eraser

II. A Ubiquitious Digital Writing System

From elementary physics, position is the second integral of acceleration.

$$s = \iint a\,dt\,dt \qquad (1.1)$$

Where s and a is the position and acceleration of the pen in the navigation frame respectively, and t is time. Hence, we can use accelerometers to measure the accelerations in the x, y and z-axes during writing, and then compute the position of the pen by the double integral according to Equation (2.1). After obtaining position as a function of time, handwriting can be reconstructed from the accelerometer output.

Owing to the advent of MEMS (Micro-Electro-Mechanical Systems) motion sensing technology, a micro-inertial measurement unit (µIMU), with dimensions of just 56 mm × 23 mm × 15 mm, can be constructed to sense the 3D motion of the pen as described before. Therefore, the overall digital writing system is very small, and it is very easy for user to take and use it at anywhere.

Micro-Electro-Mechanical systems (MEMS)

MEMS stand for Micro-Electro-Mechanical Systems which integrates mechanical units and electronic components together through micro-fabrication technology at the sub-millimetre scale. With this technology, we can build micro- structures through micro-machining and create sensors which are very small in size and suitable for the design of digital writing instruments.

There are several different methods for sensing motion. In the following sub- sections, we concentrate on discussing the working principles of accelerometers and gyroscopes used in our design of micro inertial measurement unit (µIMU).

Principle of a MEMS Accelerometer

The accelerometer is an instrument which is used to measure acceleration of a target mounted object. Two Analog Devices ADXL203 ±1.7g dual-axis iMEMS accelerometers are used in our digital writing system. There are polysilicon springs inside the which are used to suspend a beam over the surface of a silicon wafer and provide a resistance against applied force.

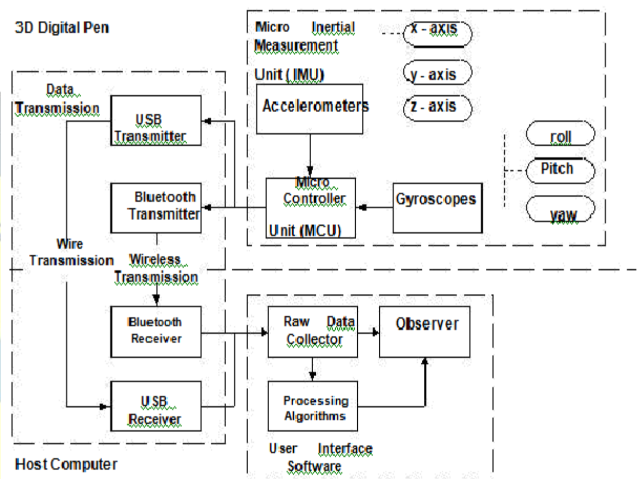

Fig.2 System Architecture of the Ubiquitous Digital Writing System

Architecture of Ubiquitous Digital Writing System

Figure 2 is a block diagram of the ubiquitous digital writing system which can be used to sense the 3D motion of a pen and reconstruct the script written by the pen on a host computer. There are three main modules which are the micro inertial measurement unit (µIMU), data transmission module and user interface software. The detailed description for each module is given in this section.

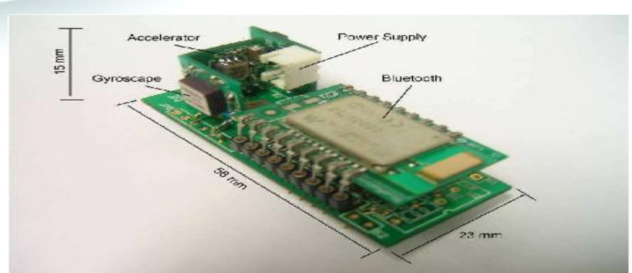

Fig. 3 The Prototype of the µIMU

Micro Inertial Measurement Unit (µIMU)

Figure 3 shows a prototype of a µIMU. An inertial measurement unit (IMU) is used to measure acceleration and angular velocity of the attached object based on its motion. The word " micro" refers the size of overall measurement unit.

Accelerometers

Two analog Devices ADXL203 precision ±1.7g dual-axis iMEMSr accelerometers are used in our µIMU. These are aligned perpendicularly along the x, y and z-axes of the body frame of the pen. They are connected to a MCU and their output signals, which are in analog format, are digitized by an analog-to-digital converter (ADC) in the MCU which is also used to transmit the linear accelerations of the pen to the host computer through the data transmission module.

Gyroscopes

Three Murata piezoelectric vibrating single-axis gyroscopes (GYROSTAR - ENC-03M) are also used along the x, y and z-axes of the body frame of the pen to measure rotational angular velocities in three rotation angles, roll (f), pitch (θ) and yaw (ψ) respectively. As with the accelerometers, they are connected to a MCU and their analog output signals digitized by the ADC to transmit rotational angular velocities to the host computer through the data transmission module.

Microcontroller Unit (MCU)

A PIC MCU is used to sample the 6 channels of accelerometers and gyroscopes at a rate of 200Hz and then digitize their analog outputs through its internal 10-bit ADC. The data are transmitted to the host computer through the data transmission module.

Data Transmission Module

A data transmission module is used to transmit sensor signal data from the µIMU to the host computer. We have two transmission modes; one is via USB and the other wireless. The host computer receives the data through a virtual serial communication port.

In the wired mode, the digital pen and host computer are connected through a USB cable. This is mainly used for system development. In actual usage, USB will be used only for recharging the pen. The wireless mode uses two zigbee modules, a transmitter and a receiver. Bluetooth is supported on many computer devices, especially mobile devices, such as laptop computers, personal digital assistants (PDAs), smart phones, etc. With an approximate range of 10 meters, users can use the pen anywhere in a room and transmit handwriting to a host computer.

User Interface Software

A user interface software as shown in Figure 4 is developed for the host computer. The software is divided into three main modules as shown in Figure 4, the raw data collector, processing algorithm and observer.

Raw Data Collector

The raw data collector module is used for obtaining sensor signal data from the µIMU through its serial port. This can receive either USB or Bluetooth data. This module is also used to segment acceleration and angular velocity in each axis and pass it to the processing algorithm module.

Processing Algorithm

The processing algorithm module is used for estimating the position of the pen from the raw data. It can be further separated into five parts as shown in Figure 2.6, zero bias compensation, attitude estimation, gravity compensation, coordinate transformation and position tracking. The detailed descriptions for these functional blocks are given below.

Observer

The observer module stores the position information and transfers it to the data display and data storage module. After collecting the position information, users can obtain the position information in two ways, the data display module can reconstruct the script and display it on the graphical user interface (GUI) of the software, or the data store module can save the position information with the raw data in a file for later reference.

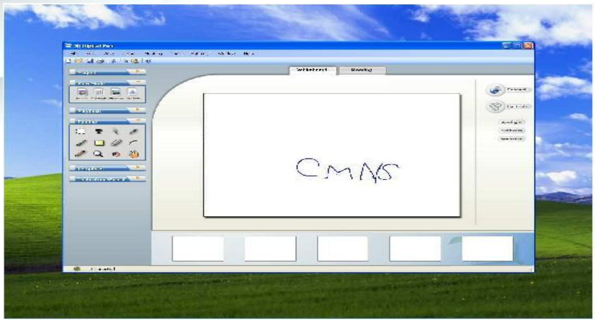

Fig. 4 User Interface Software for Ubiquitous Digital Writing System

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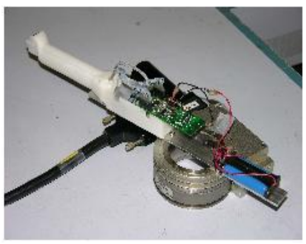
III. CALIBRATION OF µ-INERTIAL MEASUREMENT UNIT

Based on this phenomenon, we can test the accelerometers to determine whether they can provide this 90 phase difference. If not, we can supplement the remaining phase difference as a constant, i.e. $t2 = 1/_{4}T - t_{1}$when using the Direction Cos in eMatrix (DCM).



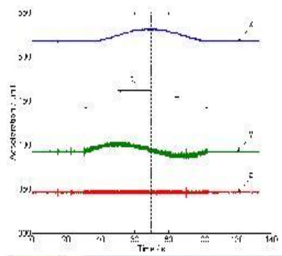


Fig 5 (a) An experimental setup for accelerometer alignment b) The experimental result of accelerometer

Quantization

Since the analog MEMS accelerometers are digitized for the ease of processing and transmission, the signal received at the host computer will be discretized and quantization errors will result.

Calibration of Accelerometers

In order to provide a full range of ±1.7g from an unsigned value, an o set voltage is added to the output. In this section, we discuss how to calibrate the accelerometer to remove o set bias and acceleration gain errors. As we know, if the µIMU is stationary, there is no external force on the µIMU except the gravity. Hence, if we obtain a maximal or a minimal output. Output $_{calibrated}$ and output $_{raw}$ are calibrated and raw accelerometer output respectively, g is the gravitational constant 9.81 ms^{-2}, and sign is defined to follow the body frame coordinate system.

Coordinate Transformation with Gravity Compensation

There are two coordinate systems of the digital writing instrument. One is the body frame, which represents the coordinate system aligned. Configuration of the accelerometers attached on the digital writing instrument. The other is the navigation frame, which represents the coordinate system we used in the navigation tracking [5, 11, and 20]. In order to reproduce the handwriting trajectory, we first need to transform the acceleration in the body frame to the navigation frame and remove the gravity for integration.

In this section, we would like to have a detailed description for the coordinate transformation with gravity compensation and also with the attitude determination.

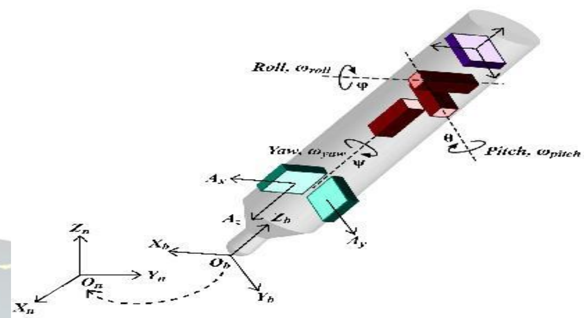


Fig.6 Coordinate system of navigation and body frames

IV. SIMULATION OUTPUT

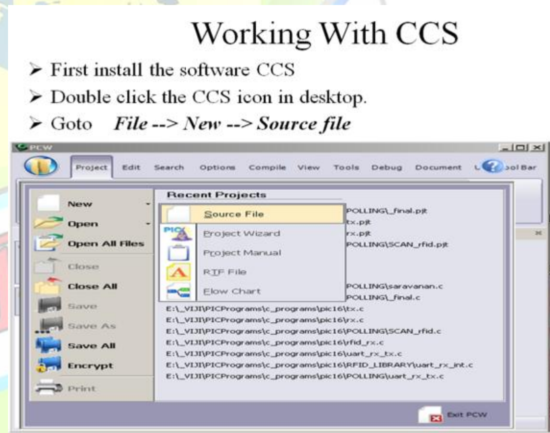


Fig 7. Simulation Output 1

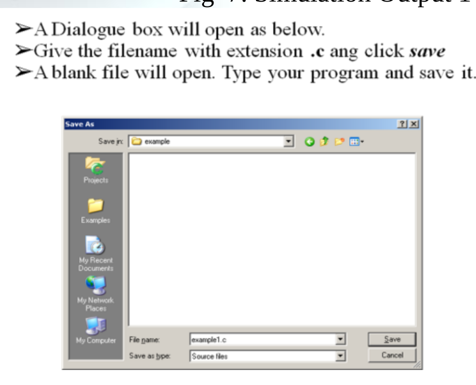


Fig 8. Simulation Output 2

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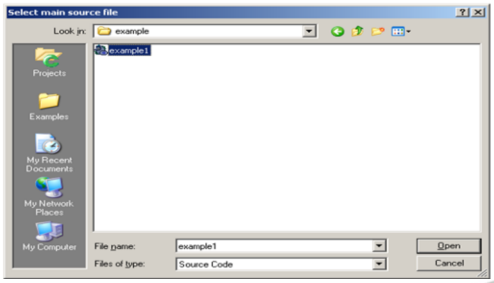

Fig 9. Simulation Output 3

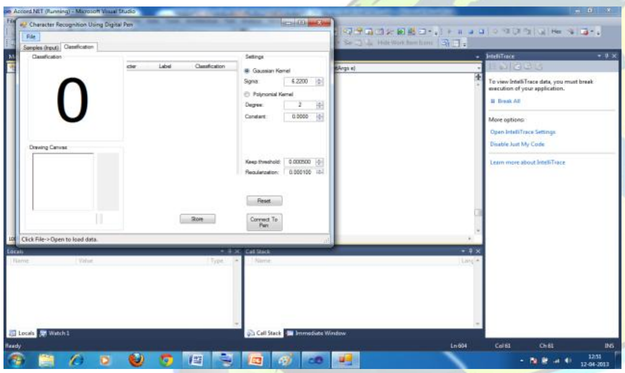

Fig 10. Simulation output 4

V. Conclusion

We developed a MEMS accelerometer-based digital writing instrument. The accelerometer picks up the acceleration generated during handwriting which is transmitted to a host computer to compute the position of the pen tip. However, as random noise degrades the acceleration readings, a positional drift results when double integration of acceleration is applied. Several error reduction schemes were investigated including zero velocity compensation (zvc) and Kalman filtering. Zero velocity compensation (zvc), proposed by the Samsung Advanced Institute of Technology, and demonstrated an ability to remove positional drift. However, a one stroke delay is introduced and it is not able to determine position in real-time.

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BIOGRAPHY

Ms.L.Megala is an Assistant professor of ECE in V.R.S college of Engineering & Technology. She completed her B.E/ECE in Idhaya Engineering College for women, Chinnasalem in the year 2008. She completed her M.E in the field of Applied Electronics in S.K.P Engineering College, Thiruvannamalai the year 2011. She is the life time member of ISTE. She has a teaching experience of 8 years. At present, she is going to have a research work in the field of Image Processing.

Mr.B.Devanathan is working as a Teaching faculty in University college of Engineering, Villupuram. He completed his B.E/ECE in V.R.S college of Engineering & technology, Villupuram in the year 2007. He did his master degree in the field of Applied Electronics in S.K.P Engineering College, Thiruvannamalai the year 2011. He has attended 6 national conferences and 2 international conference. He has a teaching experience of 9 years. At present, he is going to have a research work in the field of Digital Image Processing.