Proc. of the IEEE/RSJ IROS 2002

MIDS: Micro Input Devices System Using MEMS Sensors

Alan H. F. Lam[1], Wen J. Li[1,*], Yunhui Liu[2], and Ning Xi[3]

[1]*Center for Micro and Nano Systems, The Chinese University of Hong Kong, Hong Kong SAR*
[2]*Dept. of Automation and Computer-Aided Eng., The Chinese University of Hong Kong, Hong Kong SAR*
[3]*Dept. of Electrical and Computer Eng., Michigan State University, USA*

Contacting Author: wen@acae.cuhk.edu.hk

Abstract

The evolution of human-to-computer input devices lags far behind the evolution of processing power, i.e., the relatively "brainless" mechanical input devices such as the mouse and the keyboard are much bulkier than their state-of-the-art intelligent interfacing counterpart: the handheld PCs. In this paper, we will present our work on merging MEMS force sensors and existing wireless technologies to develop a novel multi-functional interface input system, the Micro Input Devices System (MIDS), which could potentially replace the mouse, the pen, and the keyboard as input devices to the computer. Moreover, our initial experimental results indicate that further exploration of this technology could eventually produce a new control-input device for grasping robotic manipulators. We have thus far developed a prototype MIDS that consists of two MIDS rings – each packaged with commercial MEMS acceleration sensors to sense multi-axes motion, and a MIDS wrist watch that communicates with the rings and transmits data wirelessly to interface with a CPU. The system has been demonstrated to perform click and drawing motions successfully. A self-calibration method was also developed to resolve ambiguities in sensed motion for the MEMS sensors. These results are presented in this paper.

I. Introduction

In the evolution of computer user interfaces, the mouse and the keyboard have withstood challenges from fierce competitors such as the light pen, wand, and joystick and have survived as the primary input devices. Mouse is still the preferred input device for graphical user interfaces (GUI), while the keyboard is still the most commonly used device for text-based user interfaces (TUI). Users can control the computer by using these two input devices for most applications. However, as computers become more compact and powerful, e.g., PDAs, notebooks, wearable computers, …etc., traditional designs for the mouse and keyboard may not be suitable or practical for interfacing with the miniaturized computing systems. Case in point, the size of a foldable keyboard is about twice the size of a handheld PC (PDA) – this is drastically different from the traditional PC where the keyboard is ~1/10 times the total volume of the screen and the CPU box. Obviously, the evolution of input devices lags far behind the evolution of processing power, i.e., the relatively "brainless" mechanical input devices such as the mouse and the keyboard are much bulkier than their much more intelligent and slimmer interfacing counterpart: the handheld PC.

We believe that by combining the advent in MEMS sensing and wireless technologies, it is possible to develop a novel computer input system that could enable multi-functional input tasks and allow the overall shrinkage in size of the GUI and TUI interface devices. Experimental results from our prototype input system (which has an overall size comparable to a Palm V® PDA) indicate that both GUI and TUI functions could be performed using existing MEMS-based motion detection sensors. Furthermore, we believe that this system can be further explored to control robotic grasping manipulators, hence, potentially replace the robotic gloves that are used today to interface with virtual and real robotic hands. This paper will describe the components of our system and present our encouraging initial results.

Although many computer input devices exist today, to the best of our knowledge, not many wearable multi-functional input devices are available. For instance, Prince proposed a concept to develop a finger mounted computer input device using pressure sensors in his US Patent (most likely it is a virtual keyboard [1]), but no hardware thus far have been realized. B. Thomas et al. have done an evaluation of the virtual keyboard, forearm keyboard, and Kordic keypad input devices for wearable computers [2]. The forearm keyboard and the Kordic keypad are just variations (shrinkage in size) of conventional keyboards, while the virtual keyboard requires a mouse to select individual character from the screen. Hence these technologies do not allow an user to interface with a computer as fast as the traditional keyboard and mouse. J.K. Perng et al. have developed

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[*] Contacting Author: wen@acae.cuhk.edu.hk
Center for Micro and Nano Systems
The Chinese University of Hong Kong
MMW Bldg., Room 422
Shatin, NT, Hong Kong SAR
Fax: +852 2603 6002 Phone: +852 2609 8475

an acceleration sensing glove for input text by recognizing hand-gestures [3], but only static measurements were analyzed in their system. S. Mascaro et al. have investigated a fingernail sensor to measure the finger posture and forces, which could be used to develop a virtual mouse [4][5], but the fingernail sensor is limited to sensing the applied pressure between the fingertip and a table surface, and hence can not be used in mid-air for 3-D emulation. Recently, two companies have promoted their new products at Comdex Fall 2001 (one of the largest computing-related high-tech exhibitions). Samsung introduced a novel virtual keyboard, called Scurry. Its intended use is for PDAs and wearable computers [6]. Not much technical information on the Scurry is known at this time, but from Samsung's website descriptions, we conjuncture that the Scurry is bulkier than the system we are currently developing, and may not sense position, velocity, or acceleration of the fingertips. Senseboard Technologies AB developed a new type of virtual keyboard, which allows mobile computer users to type efficiently without a physical keyboard [7], but it may not be used as a mouse or a light pen.

Our proposed system, the Micro Input Devices System (MIDS), will function as a virtual mouse, a light pen and a virtual keyboard such that it allows user to input text, move curser, control drag and drop motion, draw computer graphics (CG) on the desk or in mid-air [8]. Therefore, this novel computer-human-interface allows user to use only one input device to handle both graphical based and text based input interfaces. The MIDS is presented in the following sections.

II. MIDS: Micro Input Devices System

In terms of mobile computing, we envision the MIDS to serve the functions of the present day mouse, light pen and keyboard such that it will allow users to input text, draw graphical image, move curser, and control drag and drop motion. Potentially, a MIDS (a system made of one or more MIDS and other peripheral subsystems such as Bluethooth wireless transmitters, power-storage units, …etc) will measure acceleration, velocity, and position of the fingertips, and thus, allow users to switch between different virtual input devices based on simple and customized finger motions to switch modes. The MIDS could also be explored for applications related robotics such as to control the grasping motion of real/virtual robotic hands.

MEMS sensors play a major role in our endeavor to develop a functional MIDS due to their low-cost and miniaturized size. We propose to use MEMS sensors to measure multi-dimensional force (acceleration) of each finger and hand, and wirelessly transmit these motion data to the computer for input information process. In this paper, the first prototype of a MIDS suitable for virtual mouse, light pen and virtual keyboard functions is presented. The key subsystems of this prototype are described below.

A. System Description

Our prototype MIDS consists of 4 main subsystems: 1) the MIDS rings with MEMS multi-axes acceleration sensors, 2) the wireless transmission wrist watch, 3) the wireless transmission interface board for PC, and 4) the display interface program. The MIDS rings are worn on the fingers and are electrically connected with a wireless transmission watch on a wrist that acts as a communication link between the sensors and the CPU. Potentially, wireless links could also be established between the MIDS rings and the wristwatch. Inside the watch, a microprocessor is used to analyze the sensor signal and encode the signal for wireless transmission. Another microprocessor is placed in the wireless transmission interface board to decode the receiving data and convert the command signals to the PC. The illustration in Figure 1 shows the comparison between traditional input devices and wireless MIDS.

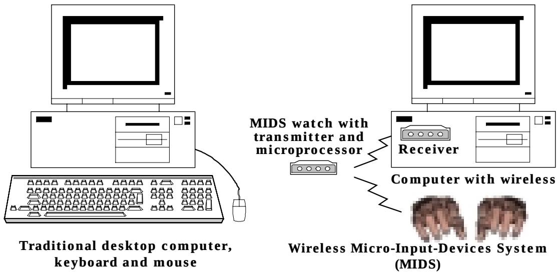

Figure 1: Configuration comparison between traditional input devices and a wireless MIDS.

There are many potential applications for this invention. Piano player can use the MIDS to play a virtual piano so that they need not to learn typing. Their piano keyboard input patterns can be transferred to the computer, which could translate and record a song or play it on the speakers directly. Another application is that users can use the MIDS to interface with a PC using conventional sign-language gestures, i.e., a users can just use sign-language motions and the computer can translate the motions into sentences without any typing from the fingers. One of the more meaningful applications for the MIDS will be its usefulness to help the blind. MIDS can help them make brail-based typing by using different finger motion patterns. When the finger motion patterns are transferred to the computer, the computer can translate those patterns to words and then save them as a document. Other applications for the MIDS will include emulation of a laser-pointer, and as a light pen for languages such as the Chinese.

With the MIDS, not only a revolution will take place for input devices, but mobile computing development may also enter another generation. It is foreseeable that virtual reality glasses will replace the monitors for mobile computers, and a MIDS can be used as input devices. Imagine this: carrying a pair of sunglasses and a very compact and powerful CPU box, wearing a wireless-linkage watch, and put on a few rings embedded with MIDS sensors and batteries – one could work conveniently in many places not possible today. Our invention will make this possible in the near future.

B. MEMS Sensors for Multi-axes Force Sensing

The most important subsystem of the MIDS is the MIDS ring. An illustration of the components of the MIDS ring is shown in Figure 2. Two dual-axis MEMS accelerometers (manufactured by Analog Devices Inc.) are mounted as shown. Sensor A is placed at the top of the ring horizontally to measure fingertip accelerations in the x and y directions. Sensor B is placed at the side vertically to detect accelerations in the y and z directions. Therefore, sensor A can detect the plane motion of the fingertip and sensor B can detect the fingertip angle (relative to rotation about the mid-joint of a finger) and the vertical movement.

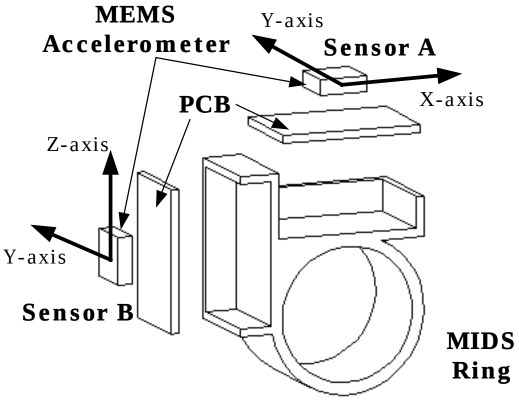

Figure 2: Schematic of MIDS Ring

C. Wearable Wireless MIDS

The first generation prototype of our MIDS has been built and is shown in Figure 3 and Figure 4. The ring-shape housing was made by a rapid prototyping machine (FDM1600 by StrataSys Inc.). Each of two MEMS accelerometers on a ring is placed on a PCB containing signal conditioning circuits. The battery cell from the wristwatch subsystem also powers the sensors on the rings.

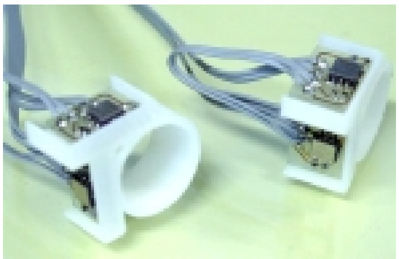

Figure 3: Prototype of MIDS rings

Figure 4 shows the entire wearable MIDS prototype. A microprocessor (AT90S8515) is used to count the duty cycles of the sensing signals and convert the signals to acceleration information. Then, the Radiometrix TX2 transmitter is used to transmit the packed signal sequentially. One the signal receiving end, the RX2 receiver passes the received data to another microprocessor, which unpacks the data and passes the suitable commands to the PC from the serial port.

Figure 4: Wearable wireless MIDS prototype.

III. Experimental Results

Experiments were performed to demonstrate the motion detection in 3D space of our MIDS. Two experiments were performed: 1) measurement of the fingertip motion in z-axis for click motion detection; 2) measurement of the fingertip movement on x-y plane to determine the trajectories of the movement as sensed by the motion sensors. The results are shown below.

A. Experimental Results of click motion test

Measurement for click motions in z-direction is shown in Figure 5, which basically shows the up and down motions of the fingertip. Three cases are distinctive in the data plot: one peak (a), two peaks (b), and three peaks (c). As indicated in the figure, the time duration for each of the sampled motion is about 1 second. Regions (a), (b) and (c) shown in the figure correspond to single-click, double-click and triple-click, respectively. These results show that the accelerometer could detect the click motions (even for triple-click) within a short time (about 1 second). The sampling frequency used for this experiment is about 31data/sec (0.0322sec/datum). The response time of the sensors are fast enough to measure the fingertip motions based on our experimental observations.

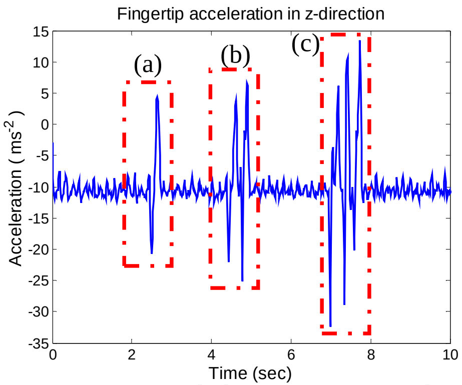

Figure 5:MIDS click motion test in mid-air

B. Experimental Results of circular motion test

The motion of a fingertip as it traverses around a circular path was also measured. (The circular path was imagined by the experimental subject; no reference circular path was placed on a table for the subject to follow.) The time-sequence data of the 2 sensors on the fingertip is shown in Figure 6, and the corresponding displace plot in the x-y plane is shown in Figure 7.

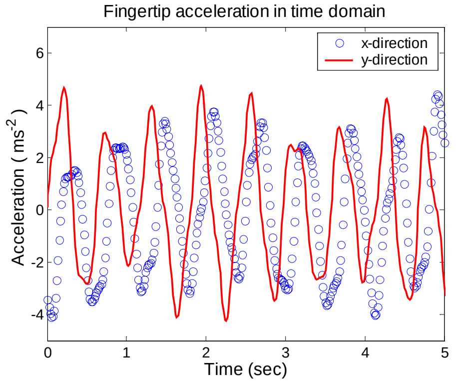

Figure 6: MIDS circular motion test on a desk (time sequence acceleration)

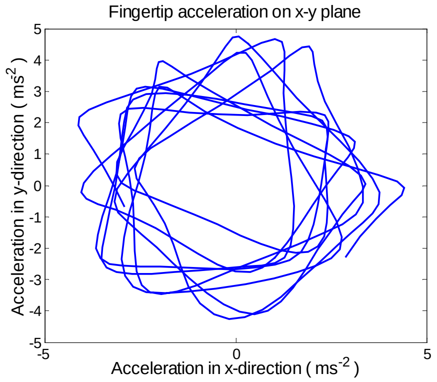

Figure 7: MIDS circular motion test on a desk

The experimental results above demonstrate that the MIDS performed excellently as the single-click, double-click, and triple-click motions could be measured distinctively. The response time of the MIDS is fast enough to record a triple-click motion within a second as shown in the figure. Moreover, experimental results, as shown in Figure 7, also indicate that the MIDS could also detect circular motion.

With the above results, we have shown that the MIDS could handle operations of existing common input devices. For the mouse, MIDS could detect the movement on x-y plane such that it could move a cursor and also handle the click motion; for the keyboard, MIDS could detect the finger movement (as a finger moves from one key to another) and the key-press action (as the finger types a key); for the light pen, MIDS could capture the trajectory of the finger such that it can draw a desired curve either in a fixed 2-D plane or in 3-D space.

IV. Multi-Functional MIDS

We have tested our prototype MIDS for three major functions: Virtual Mouse, Virtual Keyboard and Virtual Pen. To select a particular virtual device (a mode), an user may perform the procedures listed below. Note the procedures used currently are very rudimentary, and are intended to demonstrate the capabilities of the MIDS only. We will develop a more sophisticated and convenient mode-switching process in the future.

1. The default mode is the OFF mode called Mode A, which shuts all MIDS functions off.

2. When an user triple-left or triple-right clicks a finger (within ~1 sec) the MIDS will switch between modes. After the clicks, the user should stop moving the fingers for about 0.5 sec to complete the mode selection process. Hence, to switch to Mode B (Virtual Mouse Mode) from Mode A, the user needs to triple-left or triple-right clicks a finger.

3. Similarly, to change to Mode C (Virtual Keyboard) from Mode B, the user again needs to triple-left or triple-right click a finger.

4. The user needs to triple-left or triple-right click a finger again to change from Mode C to Mode D (Virtual Pen).

5. The mode sequence is A-B-C-D-A. An user may not jump between modes (e.g., from B to D) with the current setup.

V. Self-Calibration Function

Our MIDS use acceleration sensors to measure fingertip motion, and therefore, ambiguities in the sensed motion could result. For example, given a dual-axis accelerometer is placed vertically to measure motion in the y and z directions (refer to Figure 2 for coordinate definition), an ambiguity could occur in resolving a given finger motion whether as a translation or a rotation. This problem is depicted in the illustrations given in Figure 8 and Figure 9 for pure translation and pure rotation, respectively. In Figure 8, the accelerometer is translated with acceleration a_{Tran} from point A to point B via a direction that is at an angle θ relative to the y-axis. The measured acceleration in the y and z directions are a_{ty} and a_{tz} after translation, respectively. In Figure 9, the accelerometer is rotated by angle α about the x-axis, and a_{ry} and a_{rz} and are the measured acceleration signals for y and z direction after rotation, respectively. For these two cases, the acceleration signals from the sensors are equal when

$$\alpha = \tan^{-1}\left(\frac{a_{Tran}\cos\theta}{g - a_{Tran}\sin\theta}\right) \tag{1}$$

Such that,

$$\begin{cases} a_{ty} = a_{Tran}\cos\theta = g\sin\alpha = a_{ry} \\ a_{tz} = a_{Tran}\sin\theta - g = -g\cos\alpha = a_{rz} \end{cases} \tag{2}$$

Therefore, for arbitrary α, there are many possible combinations of solutions for a_{Tran} and θ such that the sensor signals for pure translation are equal to pure rotation. This means that the measured acceleration signals could represent either rotational or translational motions of the finger. We have developed a self-calibration function for our MIDS to tackle this problem such that the rotation angle α can be determined.

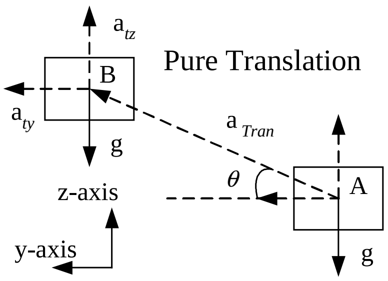

Figure 8: Pure translation measurement for a dual-axis accelerometer placed vertically from a horizontal reference plane (refer to Figure 2)

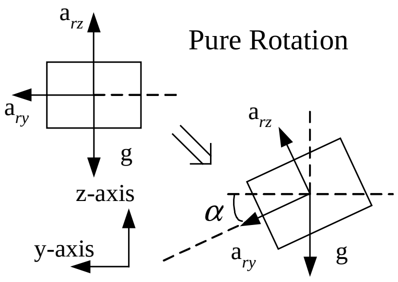

Figure 9: Pure rotation measurement for a dual-axis accelerometer placed vertically from a horizontal reference plane (refer to Figure 2)

This self-calibration function was realized without any addition of hardware – to ensure that the overall size of the MIDS can be minimized. To implement this software-based calibration, two assumptions have been made:

1. The fingers rotate only about the x-axis;
2. After the mode has been changed, the fingertip angle should remain constant such that α can be measured (for our current system, a 4 MHz processor is used, 0.5sec is required).

Hence, the angle α can be checked right after a mode change if a short period of time is allowed. This pure rotational angle α can be found by the measuring the accelerations in y and z directions:

$$\alpha = \tan^{-1}\left(-\frac{a_{ry}}{a_{rz}}\right) \tag{3}$$

With the initial angle α known, the actual acceleration in x, y and z directions and the acceleration components (on horizontal plane and along vertical axis) in the world coordinate frame (wcf) can be calculated.

Using the above self-calibration method, the actual amplitude (a_{Tran}) and relative angle of acceleration from the horizontal plane (θ) for the fingertip motion with initial angle α are:

$$\theta = \tan^{-1}\left(\frac{a_{tz} + g\cos\alpha}{a_{ty} - g\sin\alpha}\right) \tag{4}$$

$$a_{Tran} = \frac{a_{ty} - g\sin\alpha}{\cos\theta} \tag{5}$$

And, in the wcf, the horizontal and vertical accelerations are:

$$\begin{cases} a_{hor} = a_{tx}\cos\alpha + a_{ty}\sin\alpha \\ a_{vert} = -a_{tx}\sin\alpha + a_{ty}\cos\alpha \end{cases} \tag{6}$$

Experimental results for the self-calibration test of the MIDS are shown in Figure 10 and Figure 11. Two MIDSrings were used for the experiments: one with self-calibration (s-c) and one without. The rings were placed with an initial angle of 35^o off from the y-axis. Accelerations in the x direction were applied to both rings along the y-axis. As shown in Figure 10, the MIDSring with s-c gives a correct signal indicating acceleration values varying along the zero acceleration axis; however, the MIDS without s-c shows an offset acceleration of –5.8ms^{-2}. The circular path lines on the x-y plane are shown in Figure 11, and a clear offset of –5.8ms^{-2} is observed for the MIDS without s-c. These results show that the self-calibration method can eliminate the error due to the initial offset angle.

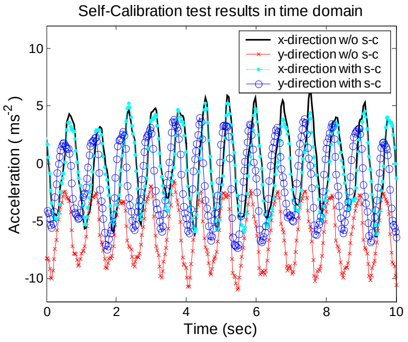

Figure 10: Comparison of measured time- sequence acceleration data between a self-calibrated MIDS ring and a non-calibrated MIDS ring

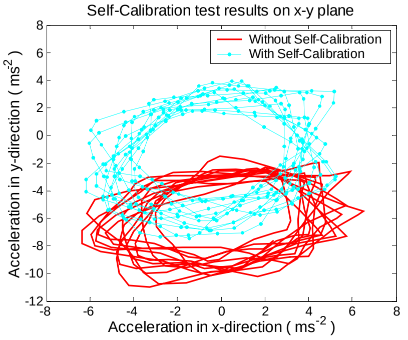

Figure 11: Comparison of measured motion in the x-y plane between a self-calibrated MIDS ring and a non-calibrated MIDS ring

VI. Conclusion

A novel multi-functional wearable micro-input-devices system has been proposed and a working prototype of this system has been demonstrated. The MIDS uses MEMS-based acceleration sensor to detect fingertip motions. The prototype system was demonstrated to perform the basic functions necessary for a virtual keyboard, a virtual mouse, and a virtual light pen. In addition, a self-calibration method was described to eliminate angular offset errors that may cause ambiguities in the sensed motion. In the short future, we will demonstrate a more advanced MIDS to emulate commercially available functions of a virtual mouse, a virtual keyboard and a virtual light pen. We will also explore the possibility of using our MIDS to control robotic grasping hands.

VII. Acknowledgement

The authors would like to thank Raymond H. W. LAM for his valuable contributions and programming support to this project. This work was funded by The Chinese University of Hong Kong and with partial support from a grant from the Research Grants Council of the Hong Kong Special Administrative Region (Project no. CUHK4206/00E).

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