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Motion Sensing for Robot Hands Using MIDS

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***Abstract* – A novel computer input system - the Micro Input Devices System (MIDS) – is under development by merging MEMS sensors and existing wireless technologies. This system could potentially replace the functions of the mouse, pen, and keyboard as input devices to the computer. The system could also be used as a general wireless 3D motion sensing device. In this paper, we will present our work on using MIDS for motion sensing application of robot hands. MIDS is used to evaluate the performance of PD adaptive control and Impedance control schemes in manipulating a five-fingered robot hand and in manipulating this hand to grasp a ball. Experimental results indicate that MIDS is capable of obtaining real-time 3D acceleration/vibration data wirelessly for the robotic hand, hence eliminating the need to perform the time-consuming integration of the position sensor data to obtain acceleration. Moreover, our initial results also indicate that further exploration of this technology could eventually produce a new control-input device for robotic grasping manipulators. These results are presented in this paper.**

I. INTRODUCTION

Nowadays, fingered robots are becoming more ubiquitous, e.g., in the manufacturing industry, robot hands are now used to handle many duplicated tasks such as grasping in product assembly line. Human-like robots such as Honda's humanoid robot: ASIMO [1] and Sony's SDR-4X [2] are commercially available in the market. These robots can be classified into two different types: controlled by the CPU automatically and manipulated by operators. For automated robot hands, motion sensing devices are essential to measuring the motion of the robot hands for quality control and system evaluation. For manual control robot hands, a user friendly input device can be useful to the operator in controlling manipulators such as grasping robotic hands. In this case, a multi-functional device is needed to handle both the motion sensing function and the control-input function. In this paper, we will show that our current research in developing the Micro Input Devices system (MIDS) will enable many new capabilities in terms of robotic sensing and control, including multi-functional device for sensing and controlling robotic hands.

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 graphical user interface (GUI) and text-based user interface (TUI) input devices. Experimental results from our prototype input system [3] and [4] (a similar input system was also proposed by K. Pister's group at Berkeley [5]) indicate that both GUI and TUI functions could be performed using existing MEMS-based motion detection sensors. 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. Moreover, this system can be used to capture the motion of the hand, e.g., the motion of the robot hands and the fingers can be detected. This means that MIDS can potentially function as an external motion sensing device to give extra information to engineers to design or modify the controller of a robotic-hand manipulation system. Furthermore, we believe that this system can further be explored to ultimately 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 results for robotic hand motion sensing experiments.

In robotics area, research in grasping using robot hands has been extensive in the past decade [6]-[9]. In order to study the dynamics of the robot hands and develop effective control algorithms for grasping tasks, K. Nagata et al. have developed a master hand for grasping information capturing [6]. Their master hand can be used to measure the motion of the human. The working principle is to measure the change of the kinetics contact between human fingers and the object so that it could give some reference information for development of grasping algorithm of robot hands. This is also one of the objectives of our project but different operation. Our proposed system, the Micro Input Devices System (MIDS), functions as a motion sensing device and control-input device for grasping robot hands. MIDS is not used to develop the control algorithm for grasping only; rather, it acts as a robot-human-interface that allows users to control the robot hands by their body motion. The details of MIDS are presented in the following sections.

II. MIDS: MICRO INPUT DEVICES SYSTEM

In terms of motion sensing, MIDS is a portable, cheap and small size motion detector for robot hands. It can give the motion information to the controller such that these data can be used to design or modify the control or the input data for neural network training scheme. On the other hand, MIDS is a wearable and multi-functional input device. Potentially, a MIDS (a system made of one or more MIDS components and other peripheral subsystems such as Bluetooth wireless transmitters, power-storage units, …etc) is able to measure acceleration, velocity, and position of the robot fingertips, and thus, allowing users to control the robot hand to do tasks such as grasping motion of real or virtual robotic hands.

MEMS sensors play a major role in our endeavour 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 prototype of a MIDS suitable for motion sensing and control-input functions for robot hand 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 MIDS controller, 3) the wireless transmission interface board connected to a PC, and 4) the display interface program. The MIDS rings are positioned on the human/robot fingers (depending on the purpose: as a motion sensing device or a control-input device) and are electrically connected with a wireless transmission controller that acts as a communication link between the sensors and the PC. Potentially, wireless links could also be established between the MIDS rings and the MIDS controller. Inside the controller, a microprocessor is used to analyze and encode the sensor signals for wireless transmission. Another microprocessor is placed in the wireless transmission interface board (which is connected to the PC) to decode the data received from the wireless controller. For the motion sensing MIDS, it passes the received data to low-pass filter before sending to the PC. For control-input device, the received data is passed to a control algorithm and then converted the command signals to the PC. A display interface program is used to plot the sensor data and the control-input commands.

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 Fig. 1.

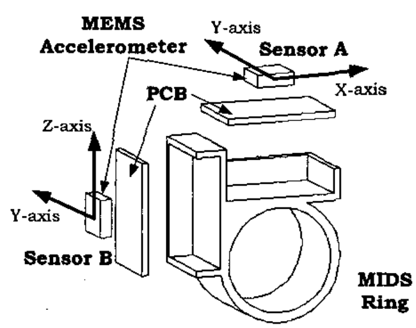

Fig. 1 Schematic diagram of a MIDS ring

Two dual-axis MEMS accelerometers (manufactured by Analog Devices Inc.) are mounted as shown in Fig. 1. 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. The sensors employ the principle of relating the capacitance variation between the polysilicon comb-drives to acceleration to detect motion (as illustrated in Fig. 2)

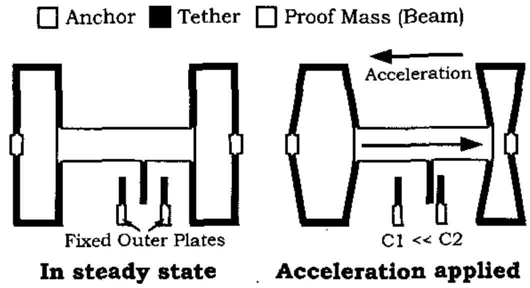

Fig. 2 Illustration of sensor operation

When movement is applied to a sensor, the proof mass is moved such that the capacitances between the two fixed outer plates (C1 and C2) are changed. The acceleration can then be determined by the ratio of the capacitances.

C. *Wearable Wireless MIDS*

The prototype of our MIDS is shown in Fig. 3 and Fig. 4. The ring-shape housing is made by a rapid prototyping machine (FDM1600 by StrataSys Inc.). The two MEMS accelerometers on a ring are connected to a signal conditioning circuits and are powered by the battery cell from the MIDS controller subsystem.

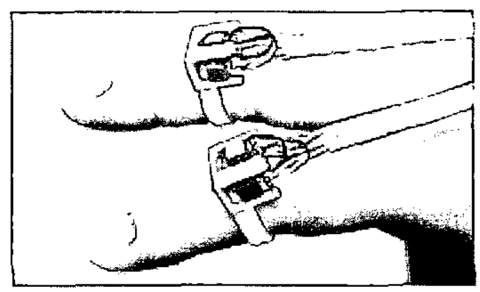

Fig. 3 Prototype of MIDS rings.

The entire wearable MIDS prototype is shown in Fig. 3. A microprocessor (AT90S8515) is used to count the duty cycles of the sensing signals and convert the signals to acceleration information. Then, a 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 suitable commands to the PC from serial port. The data acquisition schematic is shown in Fig. 5.

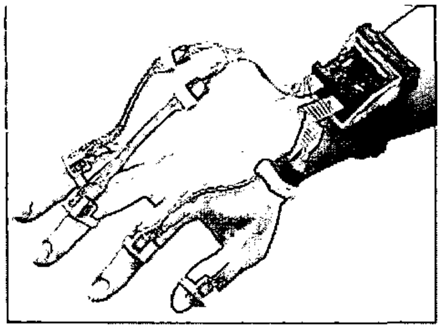

Fig. 4 Wearable wireless MIDS prototype

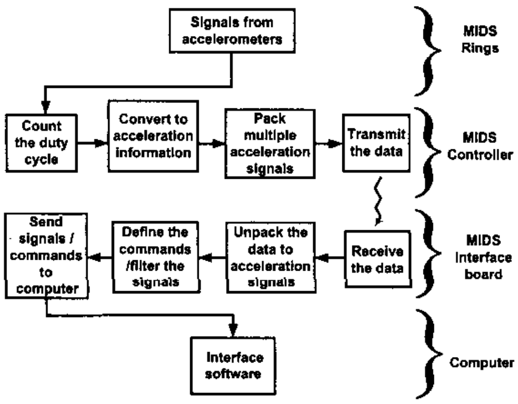

Fig. 5 Data acquisition schematic for the MIDS

The technical data of the sensors, transmitter, receiver and microprocessor is summarized in TABLE I. The resolution and the operating voltage of the overall system (MIDS) are also shown in TABLE I. The sampling frequency of MIDS is about 30 data sets per second (30Hz per data set), which is larger than the reaction rate of human (less than 20Hz), and means that MIDS is suitable for human-controlled computer input operation.

TABLE I
TECHNICAL DATA OF THE MIDS

Sensor	
Acceleration range ($1g = 9.81ms^{-2}$)	$\pm 2g$
Resolution	5mg
Bandwidth	5000 Hz
Temp. range	0 – 70 °C
Supply current	0.6mA
Transmitter and receiver	
Transmission rate	40kbps
Microprocessor	
Speed grade	4 MHz
Power consumption at 3V, 25 °C	Active: 3mA Idle mode: 1mA
MIDS	
Resolution (1 data set include 8 acceleration signals)	~30 data sets /sec
Operating voltage	3V – 6V (4.5V)
Operating power (for 4 sensors)	~ 0.025 W

III. EXPERIMENTS

Experiments were performed to demonstrate the motion detection in 3D space of our MIDS as it was used on a five-fingered robot hand. Two experiments have been performed: 1) grasping motions of two controlled systems – PD adaptive system and Impedance system and 2) grasping a ball using PD adaptive system. The results are shown below.

A. Experimental Setup

The manipulator used in the experiments is a five-fingered robot hand system at the Robot Control Laboratory of the Chinese University of Hong Kong. The robotic finger made by Yaskawa has three revolute joints driven by AC motors through a harmonic drive of 80:1 reduction ratio. The robot hand is controlled by a distributed DSP C40's system. The MIDS rings were positioned on the end-effectors of two robotic fingers. The installation and the configuration of the MIDS for the five-fingered robot hand are shown in Fig. 6 and Fig. 7. The x-y plane is parallel to the horizontal plane of the world coordinate frame and the z-axis is parallel to the vertical axis, which is consistent to Fig. 1.

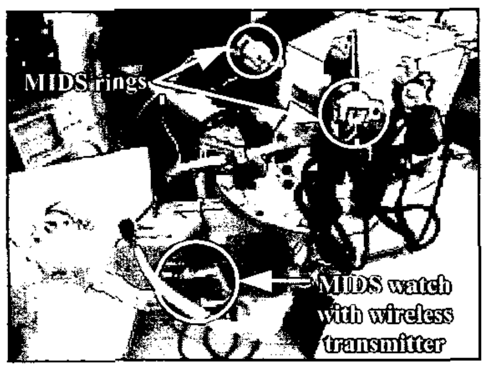

Fig. 6 Installation of MIDS for fingered robot hand

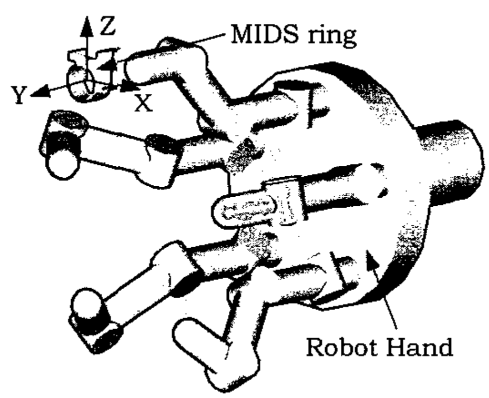

Fig. 7 MIDS configuration for robot hand motion detection

The experimental setup for the motion sensing test is shown in Fig. 8. The grasping motion is first detected by the MIDS rings. The acceleration signal then is passed to the microprocessor of the MIDS controller for signal encoding. After that, the packed signal is transmitted to the receiver through the wireless transmitter inside the MIDS controller. Once the wireless receiver receives the signal, another microprocessor inside the interface board will decode the received signal and then pass the acceleration signals to the PC through the serial port. We have also developed an interface program called MIDS Interface, which is able to display real-time signals from MIDS.

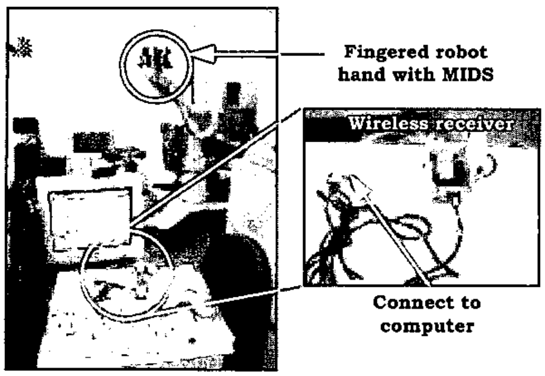

Fig. 8 Experimental setup for motion sensing of fingered robot hand

B. *Experimental Results*

The first experiment was to evaluate the performance of two control methods (PD adaptive control and Impedance control) for the grasping robot hand. The responses of the fingertip motion of the robot fingers are shown in Fig. 9. The responses are in 3D space (xyz directions as defined in Fig. 7). The results in Fig. 9 show that vibration occurred during the grasping motion. At the initial state, the acceleration values of x-direction and y-direction were $0ms^{-2}$ and the acceleration value of z-direction was $-10ms^{-2}$ (-g) due to gravity. At t = 1sec, the robot fingers rotated along x-axis from 0° to 90° and then still stayed for about 1sec, hence the acceleration values of y-direction and z-direction changed to $10ms^{-2}$ and $0ms^{-2}$, respectively. After that, the robot fingers returned to the initial position following the same path and kept moving periodically. In the whole process, vibrations in xyz-directions (especially in x-direction) for both PD adaptive system and Impedance control system were observed. However, the frequency and the amplitude of the PD adaptive system were higher than the Impedance control system. According to these results, the Impedance control system is slightly better than PD adaptive system. From this experiment, we have shown that the MIDS could be used as a wireless motion sensing device for a robotic grasping system. The experimental data can be used for control algorithm design or neural network training. In the short future, the control-input function of MIDS will be demonstrated for controlling the grasping robot manipulators.

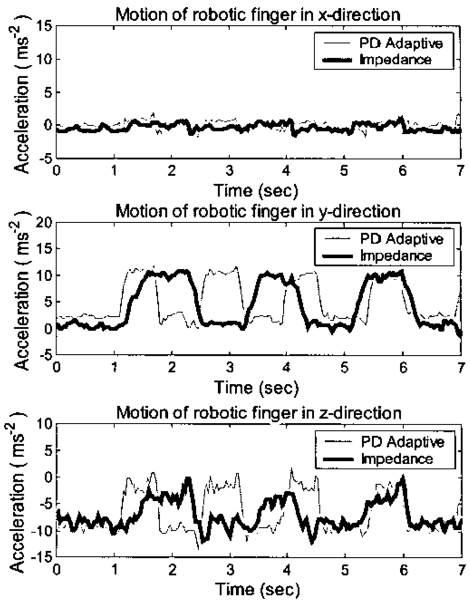

Fig. 9 Experimental results for the grasping motion of robot hand measured by MIDS

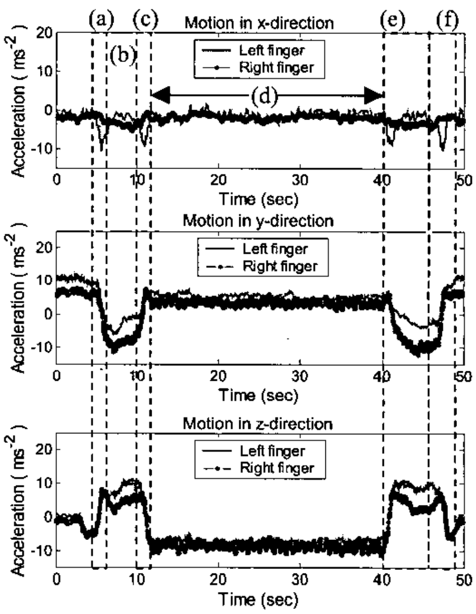

Fig. 10 Results of "Grasping a ball" experiment

The second experiment was to measure the response of the robot hand grasping a ball. The process of the experiment for robot hand grasping a ball is shown in Fig. 11. The robot hand first moved to the top of the ball and then grasped the ball. After holding the ball, the robot hand moved to the original position and then rotated the ball. After that, the robot hand moved down again to release the ball to the original position. The process of grasping motion started from (a) and ended at (f) in Fig. 11. The corresponding signals of the process from (a) to (f) can be seen in the Fig.

10. The responses of two robotic fingers in xyz direction are shown in Fig. 10. As shown, the acceleration variations during the time period from 4sec to 12sec and from 40sec to 48sec were very obvious. This is because the robot hand had moved from top to down to grasp the ball and then released the ball. The reason of the signals in the x-direction keeping nearly constant is that the motion of robot moving up and down was rotated by x-axis. For the left finger, there was an offset angle along z-direction so that the MIDS could measure a fraction of movement for the duration of the move period. During the grasping period (from 4sec to 6sec), a pulse in x and z directions was measured because the finger was rotated along the y-axis to grasp the ball. For the same reason, during the release of the ball, pulses in both x and z directions were measured (from 46sec to 48sec). From 12sec to 40sec, the ball was rotated. The vibration of the fingers during this rotation motion could also be measured.

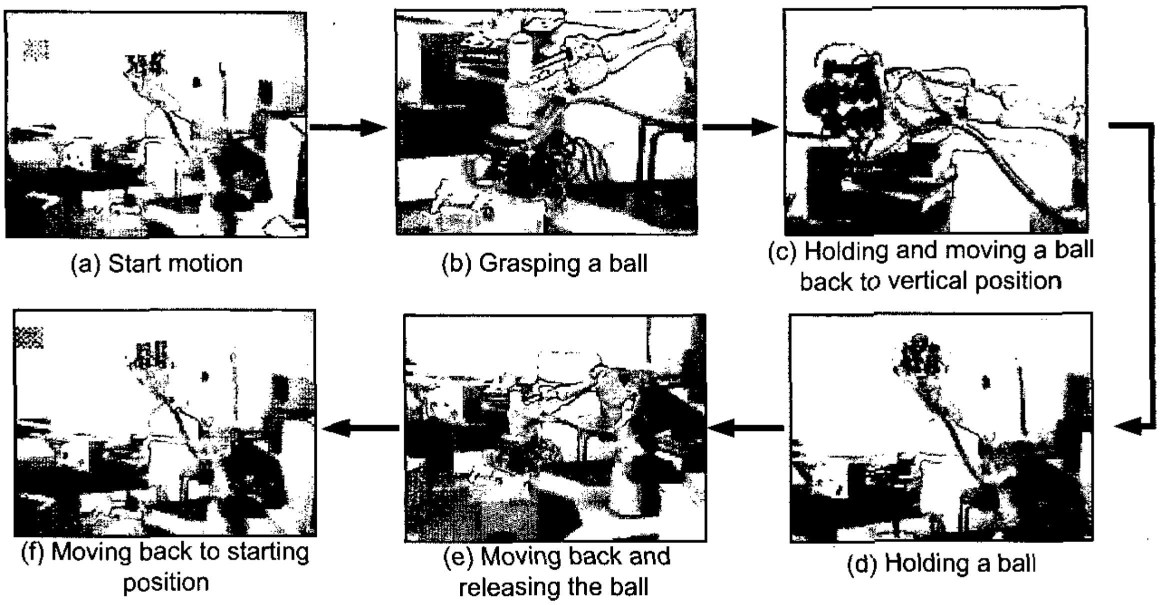

Fig. 11: Process for the second experiment: grasping a ball

IV. POTENTIAL APPLICATION

Many control methods, such as the PD adaptive control and the Impedance control, focus on the position and force control without considering vibration. According to the results of previous section, vibration problems still transpire in these position and force control methods. For instance, using a robot hand with traditional control methods, such as position and force control, to carry and transport a glass of water from point to point exhibits a high possibility of spilling due to vibration.

Currently, to obtain vibration or force information for the type of robot hand system tested above, we can use the encoders in the finger joints to measure the position and then calculate the second derivatives to get the acceleration values. These acceleration information can then be used to improve the control algorithm. However, the error can be significant due to differentiation of the collected data.

Another method is to install some accelerometers to measure the vibration. And then the measured signals can be fed back to a new controller that considers the acceleration. However, it is quite costly to install extra sensors to existing systems, and some systems may not be suitable to install extra sensors.

Our portable MIDS can be helpful for this purpose. It is easy to install the MIDS in the existing robotic system by using suitable design of rings. Then the MIDS can directly measure the acceleration of each finger. However, it is still costly to install MIDS to robotic systems with multiple machines.

Based on the needs of market, we proposed a method which allows the collection of acceleration information for many robotic systems while maintaining the cost at a reasonable level. Normally, most of the industrial robots, especially those serve in the factory assembly line, are trained to perform the same tasks in cycle, resulting in the anticipated repeated acceleration patterns. And also, there are many robotic systems in which joint angle sensors have been installed inside the robot hand for measuring the finger angles. Then the positions of the fingertips can be calculated by the joint angles. However, calculating second derivatives of the positions to get the accelerations faces the drawback of significance degeneracy for highly non-linear systems. In this case, we proposed a control algorithm using neural network to tackle this problem. Neural network training method can be used to get the mapping from the sensors' readings to the accelerations. The accelerations can be measured by our portable MIDS. Once the neural network model is built, it is not necessary to measure the acceleration anymore. After training, the MIDS can be removed from the machine because the acceleration values can be obtained directly by the neural network model. The neural network model can find the corresponding acceleration patterns based on the positions measured by joint angle sensors. Therefore, only one MIDS is required to provide the acceleration information to many robotic systems during the neural network training period. An illustration of a sample control algorithm using the above method is shown in Fig. 12. Hence, Our MIDS is a flexible motion sensing device for many robotic systems.

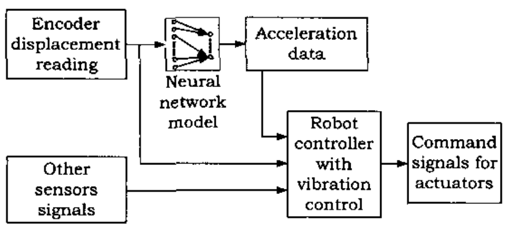

Fig. 12 A proposed Neural Network control system for robot hand fingertip with vibration control.

Since high accuracy joint angle sensors have been installed in the robot hands of most robotic systems, positions of the fingertips can be obtained by the joint angles. So, it is not necessary to do the integration for the acceleration signals from MIDS to get the velocity and displacement information for this kind of application. In the future, the acceleration integration will be discussed for other applications and using MIDS to control the robotic hand system will also be demonstrated.

V. CONCLUSION

A multi-functional portable micro input devices system has been successfully demonstrated to sense various motions of a grasping robot hand. The MIDS uses MEMS sensor to detect robot fingertip motions. Experimental results for testing two different control algorithms of a grasping robot hand and the grasping motion of a ball have been presented. The results indicate that the MIDS is applicable of measuring motion for robot hand systems. In the future, we will demonstrate the control-input function of MIDS for controlling a robotic grasping hand.

IV. ACKNOWLEDGMENTS

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V. REFERENCES

[1] http://world.honda.com/robot/

[2] http://www.watch.impress.co.jp/pc/docs/2002/0320/sony.htm

[3] Alan H. F. Lam and Wen J. Li, "MIDS: GUI and TUI in mid-air using MEMS sensors", *in Proceedings of the International Conference on Control and Automation*, June 2002, pp. 1218-1222.

[4] Alan H. F. Lam, Wen J. Li, Yunhui Liu, and Ning Xi, "MIDS: Micro Input Devices System Using MEMS Sensors", *in Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems*, Switzerland October 2002, pp. 1184 - 1189.

[5] J. Perng, B. Fisher, S. Hollar, K. S. J. Pister, "Acceleration sensing glove," *in Proceedings of ISWC International Symposium on Wearable Computers*, San Francisco, Oct. 1999.

[6] K. Nagata, F. Saito, and T. Suehiro, "Development of the master hand for grasping information capturing", *in Proceedings of 2001 IEEE/RSJ International Conference on Intelligent Robots and Systems*, Oct. 2001, vol.3, pp. 1757 –1762.

[7] Dan Ding, Yun-Hui Liu, J. Zhang, and A. Knoll, "Computation of fingertip positions for a form-closure grasp", *in Proceedings of 2001 IEEE International Conference on Robotics and Automation*, May 2001, vol. 3, 2001pp. 2217 –2222.

[8] Y. Hasegawa, J. Matsuno, and T. Fukuda, "Regrasping behavior generation for rectangular solid object", *in Proceedings of 2000 IEEE International Conference on Robotics and Automation*, April 2000, vol.4, 2000 pp. 3567 –3572.

[9] C.C. Cheah, H.Y. Han, S. Kawamura, and S. Arimoto, "Grasping and position control for multi-fingered robot hands with uncertain Jacobian matrices", *in Proceedings of 1998 IEEE International Conference on Robotics and Automation*, May 1998 vol.3, pp. 2403 –2408.