

Gyro-Mouse for the Disabled: ‘Click’ and ‘Position’ Control of the Mouse Cursor

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Abstract: This paper describes a ‘gyro-mouse’, which provides a new human-computer interface (HCI) for persons who are disabled in their upper extremities, for handling the mouse-click and mouse-move function. We adopted the artificial neural network to recognize a quick-nodding pattern of the disabled person as the gyro-mouse click. The performance of our gyro-mouse was evaluated by three indices that include ‘click recognition rate’, ‘error in cursor position control’, and ‘click rate per minute’ on a target box appearing at random positions. Although it turned out that the average error in cursor positioning control was 1.4-1.5 times larger than that of optical mouse control, and the average click rate per minute was 40% of the optical mouse, the overall click recognition rate was 93%. Moreover, the click rate per minute increased from 35.2% to 44% with repetitive trials. Hence, our suggested gyro-mouse system can be used to provide a new user interface tool especially for those persons who do not have full use of their upper extremities.

Keywords: Click, gyro-mouse, mouse-click, mouse-move, position.

1. INTRODUCTION

With the advent of the information era, there are ever-increasing demands for accessing computers and the internet. People even use computers for shopping and banking and it is expected that more household chores will be handled through computer operations. In particular, computer access is far more urgent for

those people who have lost physical mobility in their upper extremities due to accidents, or cerebral apoplexy. However, those who do not have normal use, or have paralysis of their upper extremities such as C4~C5 paraplegics, hemiplegics, and cerebral palsy sufferers cannot efficiently access human-computer interface (HCI) devices such as a keyboard or a mouse. Although there exist commercial devices for imitating an input interface with movement from the head or eyes (Headmouse, Headmaster, Headway, TrackIR, Gyrotrack, Cymouse), they require an additional switch manipulation for mouse-click that is not available for those persons having disabled upper extremities. Thus, a new and practical interface method including mouse-click and mouse-pointing operation is required.

One category of HCI for the disabled is utilizing bio-potentials such as EEG [1-3] and EOG [4-6] as an input signal. But all these methods require physical electrode-contact that limits their practical usages. Moreover, no precise information is available from the EEG signal and the fatigue of eye muscles and the dryness of the cornea limits the usage of the EOG method. The other category of HCI for the disabled is the application of sensors such as a magnetic-sensor, tilt-sensor, gyro-sensor, and infrared (IR) transceiver to detect the user’s intention [7]. In principle, the two operations of ‘positioning’ or ‘pointing’ and ‘click’ are required to control the computer mouse interface. Usually, one type of sensor was used to generate only a single function, i.e., ‘positioning’. Examples of

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these devices are the infrared head-operated joystick [8], eyeglasses-mounted IR keyboard [9], video camera- or IR-based tracking system [10,11], and gyro-sensor based addressing system [12]. Although fixing of the head or eye-gazing for a moment can be interpreted as a click operation, the response time is not desirable.

On the other hand, two different types of sensors can be combined to implement both mouse positioning and click operations. However, the composite system is usually bulky and cosmetically undesirable. Examples are tilt-sensors and touch switch [9], gyro-sensors and infrared sensor [13,14]. There were also trials to implement the composite functions with the single type sensor. Examples are the scanning letter-input system using FASTRAK [15] and the video-based menu-selection system using eye-gaze for positioning and blinking for selection [16]. However, the sensor systems used in these studies are intrinsically bulky and hardly portable and wireless.

Reviewing the aforementioned studies, the motivation of our study is clear. We aim at creating a new HCI device that controls the position and click of a computer mouse by using only one type of sensor. In this fashion, our system can be small, convenient to use, and also easy to implement in wireless configuration. To reduce the physical dimension of our system, we adopt gyro sensors to detect head movements of the user. Also, two functions of 'mouse-click' and 'mouse-move' must be implemented without considering any additional sensor information. For the criteria, the quick nodding pattern was acknowledged by neural network and the click of the mouse as well as the head up/down and right/left movements were used for the positioning of the mouse. From now on, we will refer to our suggested HCI mouse system for the disabled as a 'gyro-mouse'. The performance of our gyro-mouse system was evaluated and compared with that of the optical-mouse by three criteria such as click recognition rate, error in cursor position control, and click rate per minute of a target box appearing at random positions.

2. METHODS

2.1. Implementation of Gyro-Mouse Interface

Fig. 1 shows the structure and signal flow of the whole system. Our suggested mouse interface system was composed of a hardware unit (left) and a software one (right). The hardware unit was composed of the sensor module detecting the head movements, the microcomputer module performing A/D conversion, and serial data transmission.

Because the mobility of the patients is often limited, a blue-tooth wireless communication protocol was used for serial communication between the hardware

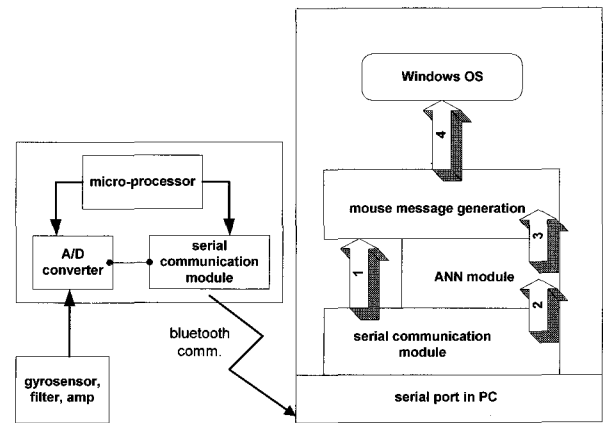


Fig. 1. Structure and signal flow of the whole system.

and the PC. The software in the PC receives the serial data and converts it to mouse messages (move and click), after which it transmits them to the Windows operating system (OS). Specifically, the click signal is generated by an artificial neural network (ANN), which detects the quick-nodding movement.

Finally, OS recognizes the user's head operation just as a mouse would and all the mouse-mediated operations of a computer become available.

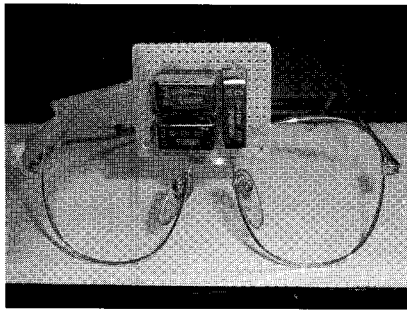
2.1.1 Hardware unit

As a small, light and high-speed sensor was required for measuring the head movements, Tokin's CG-16D Ceramic Gyro was selected. Two sensors were installed on two different axes to detect the head movements of right/left and up/down and they were attached to glasses considering superior cosmetics and convenience of 'donning' and 'doffing'. A band-pass filter was attached to the sensor to eliminate baseline drift, offset and noise. Much care was required in the design of the high pass filter (HPF). The signal from the gyro-sensor during head movement resides mostly in the low frequency bands. Therefore, the cutoff frequency of the HPF should be set at a very low value (0.003Hz); otherwise, an artifact appears because of the loss of low frequency component. Fig. 2 shows our implemented prototypes with sensor-mounted glasses.

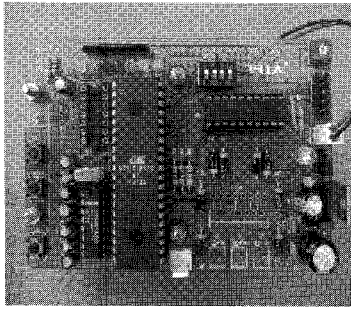
2.1.2 Software unit

The software unit was composed of off-line and on-line operation modes as shown in Fig. 3.

The off-line training mode is executed just once before the online mouse control mode. For the off-line mode, the artificial neural network (ANN) system is trained by the pre-selected training signals. For the on-line mouse control mode, the sensor data is fed to both the click detection routine and the mouse position control one. Finally, two kinds of messages, mouse-move and mouse-click, are transmitted to the OS. The click detection is implemented by ANN of



(a)



(b)

Fig. 2. (a) The prototype of our Gyro-Mouse Interface, (b) its micro-processor module.

the 3-layered perceptron model [17] with 10 and 15 neurons for the input layer and hidden layer, respectively. Each neuron activates a sigmoid function and the error-back-propagation scheme is used for the training algorithm with training termination condition. The error, E is less than 10^{-4} . The input vector (pattern) to ANN was defined as ten time-shifted data of the up/down gyro-sensor as shown in (1), where offset elimination and scaling were performed to prevent the network saturation.

$$\begin{aligned} \tilde{\mathbf{y}} &= [\tilde{y}(n), \tilde{y}(n-1), \dots, \tilde{y}(n-9)] \\ \tilde{y}(n) &= (y(n) - 100) / 20.0 \end{aligned} \quad (1)$$

Here, $y(n)$ represents the sampled 8-bit digital signal from the up/down gyro-sensor. As indicated in Fig. 3, our ANN system was configured to have just one output neuron, whose value represents click or non-click. If the output value is near '1' it is regarded as a click, if not, it is regarded as a non-click.

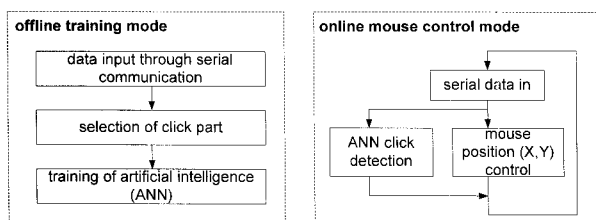


Fig. 3. The flowcharts of an offline and an online mode, respectively.

In the off-line learning mode, three signal vectors of intentional nodding and seven noise vectors of free movement are chosen as the training input patterns and the desired output is set to '1' and '0', respectively. The typical example of the input patterns to train ANN is shown in Fig. 4. The error index E was defined as

$$E = \frac{1}{2} \sum_{k=1}^{10} (t_k - o_k)^2, \quad (2)$$

where

t_k : the desired output for k^{th} input pattern (1 or 0)

o_k : the output of ANN for k^{th} input pattern.

The weights W_{ij} of the ANN are renewed iteratively to minimize E by the error-back-propagation method as in (3), where both the coefficients α and β are experimentally determined as 0.7. The learning process (3) is repeated until E becomes smaller than 10^{-4} .

$$W_{ij} \leftarrow W_{ij} + \alpha \delta_j a_i + \beta \Delta W_{ij}, \quad (3)$$

where

i : an index of the neuron at the departing layer of the connection,

j : an index of the neuron at the destination layer of the connection,

W_{ij} : weight between neuron i and neuron j ,

ΔW_{ij} : a momentum of weight modification,

δ_j : error signal of neuron j which is $a_j(1 - a_j)e_j$,

a_j : the output of j^{th} neuron on the destination layer,

e_j : the output error (output layer) or the back propagated error (hidden layer),

α : a learning rate coefficient,

β : a momentum coefficient.

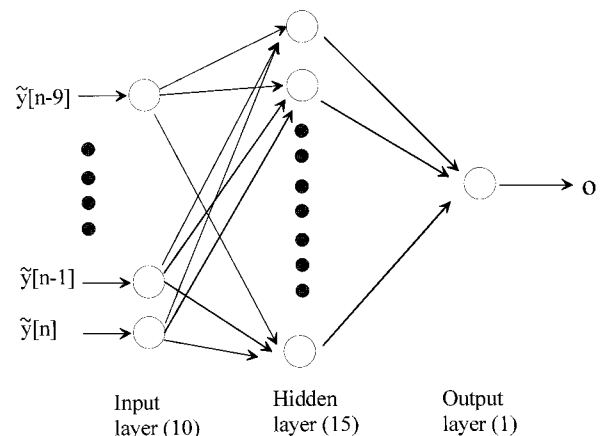


Fig. 4. Our ANN system model for mouse click recognition.

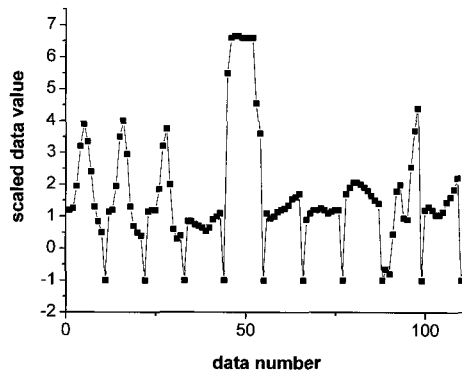


Fig. 5. Example input patterns of the click and non-click selected from the up/down gyro-sensor movement.

The learning time of ANN was short enough to be less than one second in all subjects with the Pentium IV 1.6GHz, 256M RAM PC computing system. Fig. 5 shows the results of our ANN system for recognizing input patterns of the click and non-click selected from up/down gyro-sensor movement.

In Fig. 5, the first three patterns are for the click and the latter seven patterns are for the non-click. Also, the value of '-1' is used to denote the end of each input pattern and is an actual weight for the additional bias input. One can see that each input pattern is obtained from ten time-shifted data of the up/down gyro-sensor. The first three patterns clearly are considered as 'nodding' and the rest of the seven patterns can be regarded as 'non-nodding' action. One can argue that some of the seven patterns (especially the 5th and 9th pattern) are similar to that of the first three patterns and consequently, can have a chance to be classified as 'nodding'. In our study, the ANN model system accepts each subject-specific 'nodding' click pattern with non-click body movement in the training stage. Thus, the weights of the ANN model are tuned to each subject-specific movement in the training stage and it can recognize the subtle difference in nodding or non-nodding pattern of the identical subject. As a result of that, we can classify especially the 5th and 9th pattern as non-nodding action.

For the on-line mouse control mode, the weights of ANN acquired from the off-line training process are retained to generate the ANN output from the online up/down gyro-sensor signal. If the value of neuron at the output layer is within 3% of 1, i.e., above 0.97, the input vector is recognized as a 'click' and the mouse-click message is generated. In our ANN model, each neuron activates a sigmoid function and consequently the output can be the exact value of '1'. Thus we have to adopt a threshold value for deciding '1' pattern. We set this value by trial-and-error with minimizing false-positive rate. The initial cursor position of the nodding movement is used as the location of the mouse-click message.

The position control of the mouse cursor is performed in parallel with the click recognition as in Fig. 6. The position control method adopted in this study belongs to the absolute pointing method, so the cursor movement speed is proportional to the angular velocity of the head movement. The absolute pointing renders faster and more intuitive interface than the relative pointing device such as a joystick. To prevent the cursor from responding to a small noise, we set the input dead-band as 115~125 in digital value, which is equivalent to 2.3V~2.5V in analog output of a sensor.

2.2. Performance evaluation

The performance of our developed gyro-mouse system is evaluated by the following three criteria: the click recognition rate for the evaluation of the ANN in click detection, the error in cursor position for the evaluation of the position control, and the click rate of a target box appearing at random position for the evaluation of overall performance. Five normal subjects (25.4 ± 2.9 years old) are allowed to manipulate an optical mouse. The performance of the gyro-mouse is compared with that of the optical mouse when the normal subjects operate it. This comparison would indirectly show the performance of gyro-mouse operation by patients compared to the performance of optical mouse operation by ordinary subjects, presuming the patients retain intact head and neck functions.

Experiment 1: Evaluation of the click-recognition rate

After training of ANN for each subject, the number of clicks recognized by ANN was recorded among 20 click-intended head movements on a square target box of 30 pixels on one side. Each subject takes this test four times, from which the average click-recognition rate is calculated. Of course, the real performance evaluation must be done with activating both click and position control. However, we first want to check the click recognition rate separately followed by the position control evaluation as stated in Experiment 2.

Experiment 2: Evaluation of the position control of a mouse cursor

For the evaluation of the efficiency in position control, we instructed the subject to manipulate a mouse cursor to track a target box in a test window of a square with 329 pixels on one side as shown in Fig. 6. One test trial was composed of two experiments: one with the target box moving on the horizontal line and the other on the vertical line. The time for one experiment is set at 4 seconds. Each subject is requested to repeat the trial four times. The tracking error was defined as the root-mean-squared (RMS) error between the position of the target box and the mouse cursor. The performance of the gyro-mouse was then evaluated by comparing the error of the gyro-mouse with that of the optical mouse.

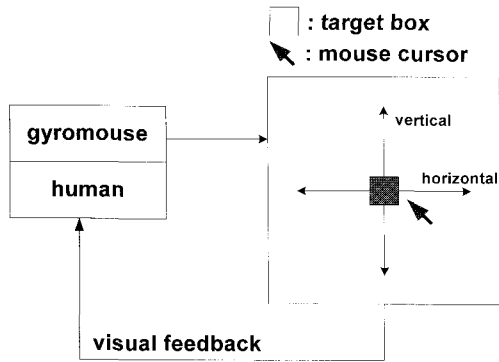


Fig. 6. Evaluation of horizontal and vertical position control of the mouse cursor (Experiment 2).

Experiment 3: Comprehensive evaluations of click and position control

A 'click-and-move' test was designed in order to comprehensively evaluate the overall mouse control, i.e., both 'mouse-click' and 'mouse-move'. As shown in Fig. 7, a subject first displaces the mouse cursor onto the square target box and makes a click, and then the target box appears at the next random position. The subject was requested to repeat the displacement and click as many as possible in one minute. The test window was a square with 329 x 329 pixels. Each subject took the trial once a day followed by the learning of ANN and the trials continued for three days. We included the following two test categories in one trial. First, the performance of both the gyro-mouse and optical mouse was evaluated and compared. Secondly, we set up two sizes of square target box (30 pixels x 50 pixels) for the purpose of determining the keypad size in the future extension of the gyro-mouse, i.e., letter-input system. The vertical length size of the program icon appearing when we click the start button in Windows 2000 is about 30 pixels. And the size of the file icon in Windows-2000 explorer is about 50 pixels. All the experiments were performed with 1280 x 1024 resolution of a 21" CRT screen.

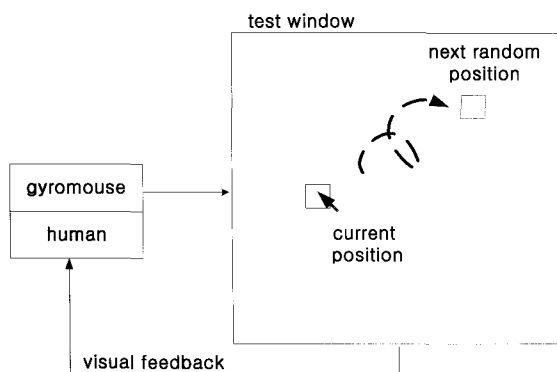


Fig. 7. Evaluation of mouse click and move control performance (Experiment 3).

3. RESULTS

Table 1 presents the test results of our Experiment 1, which was the test of click recognition by ANN after the learning process. The recognition rates were all over 90% and the average recognition rate was 93%. There was no false-positive recognition of click in all trials and all subjects.

Table 2 shows the result of Experiment 2, which was evaluating the tracking error in the cursor position control, averaged for all the subjects. The tracking errors of vertical and horizontal direction were statistically insignificant ($p > 0.4$ by student t-test) in both the gyro-mouse and the optical mouse. The average tracking error of the gyro-mouse was 1.4 and 1.5 times of the optical mouse in the vertical and horizontal directions, respectively.

Table 3 and Table 4 show the results of Experiment 3, which was the comprehensive evaluation of click

Table 1. Recognition rate (%) of the intentional click in Experiment 1.

Subject	1	2	3	4	5	Avr.
Recognition	94±7.5	96±2.5	90±4.1	93±6.5	93±2.9	93±5.1

Table 2. Average tracking errors in Experiment 2.

Tracking direction	Vertical		Horizontal	
	Optical	Gyro	Optical	Gyro
Tracking error*	11.5±2.3	15.7±5.0	10.9±2.1	16.5±4.2
Error ratio**	1.4		1.5	

*tracking error: average±standard deviation of all subjects in pixels

**error ratio = (tracking error of gyro-mouse) / (tracking error of optical mouse)

Table 3. Click rate for different sizes of click box in Experiment 3.

Target box size	30 pixels		50 pixels	
	Optical	Gyro	Optical	Gyro
Average click rate	66±11	22±7	75±15	30±7
Performance ratio*	33%		40%	

*Performance ratio = click rate of gyro-mouse / click rate of optical mouse.

Table 4. Click rate in each trial of Experiment 3.

Trial number	1st			2nd			3rd		
	Gyro	Optical	Performance ratio*	Gyro	Optical	Performance ratio*	Gyro	Optical	Performance ratio*
Click rate [clicks/min]	27±6	74±13	35%	30±8	76±16	40%	33±6	75±15	44%

*performance ratio = click rate of gyro-mouse / click rate of optical mouse.

and position control. Table 3 presents the average click rates for different sizes of click box appearing at random positions. Both the gyro-mouse and the optical mouse showed more click rates ($p < 0.01$ by student t-test) with the 50 pixel target box than with the 30 pixel target box. Moreover, the gyro-mouse performance ratio with the 50 pixel target box was 7% better than the result with the 30 pixel target box.

Table 4 shows the average click rate in each trial with the 50 pixel target box appearing at random positions. There was no significant difference between click rates of trials in case of the optical mouse ($p > 0.20$ by student t-test). However, the click rates of the gyro mouse monotonically and significantly increased with trial number ($p < 0.01$ for the first and third trials, by student t-test). Therefore, the gyro-mouse performance ratio also increased with trial number, from 35% to 44%.

4. DISCUSSIONS

This research aimed at the design and the evaluation of a new interface gyro-mouse for patients without proper use of their upper extremities. The learning time of ANN in the software was less than one second so it would have little problem in practical usage.

The performance of the system was evaluated by three criteria that are click recognition rate, error in cursor position control, and click rate of the target box appearing at random positions. The average click recognition rate was 93% (Table 1), which means 93 of 100 nodding movements are successfully recognized as clicks. The average error in cursor position control was 1.4~1.5 times that of optical mouse (Table 2). For the performance of click-and-move, a bigger target box was better than a smaller target box (Table 3). Moreover, the performance ratio increased monotonously with progressing number of trials, from 35.2% in the first trial to 44% in the third (Table 4). We believe that the improvement of performance results from the user's reproduction of the nodding pattern, with the repetition of trials. The maximum performance with the gyro-mouse was 79% (53 clicks/minute) in one subject who continued the trials 10 times. Considering all of the above, the performance of the gyro-mouse is acceptable with the icon box being bigger than usual and it is better with the repetitive use for patients who have disabled upper extremities.

One can think that it is possible to mistake a 'moving' for 'clicking' when the user makes a fast up and down movement. However, we do not have any false-positive detection under these circumstances because we include head movement (non-intentional nodding) in our training patterns and consequently this pattern is not recognized as a click move.

5. CONCLUSIONS

The gyro-mouse system suggested in this study provides a user-friendly interface recognizing the nodding pattern of each user without forcing the user to practice pre-determined operation. Moreover, the rotation and nodding of the head used in the gyro-mouse interface are common and easy movements.

The performance of the gyro-mouse was acceptable as an interface for the disabled: approximately 93% of click recognition, the positioning error of 1.4~1.5 times that of the optical mouse, and the click rates of 40% that of the optical mouse on randomly appearing 50-pixel target boxes. We believe that the relative poor performance in terms of click recognition compared with an optical mouse is due to the inherent lack of position control in the gyro-mouse. However, the performance improved significantly with repetitive trials as shown in Table 4, which implied the gyro-mouse became convenient to be used with repetitive usage.

We propose that our gyro-mouse system can achieve 'mouse move' and 'click' action with utilizing only one gyro sensor. Moreover, our ANN decision system has adapted each user-specific nodding movement pattern. Thus, the performance can be improved significantly with repetitive trials as shown in Table 4, which implied the gyro-mouse became convenient to be used with repetitive usage. We believe that our gyro-mouse would provide the disabled with not only the interface for a computer but also an assistive tool for participating in society. It is also expected that the gyro-mouse be easily applied to the field of controlling the environment and the assistive-device such as an electric wheelchair or an assistive robot.

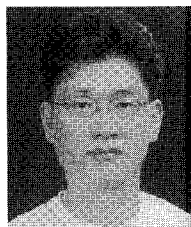
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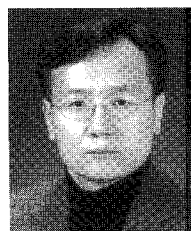
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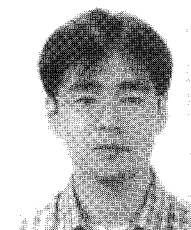
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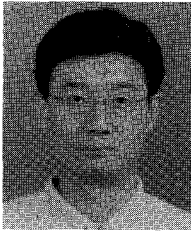
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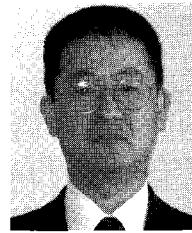
Chul-Seung Kim received the B.S. degree in 2002 and his M.S. degree in 2004 at the School of Biomedical Engineering from Konkuk University, Chungju, Korea. He is currently a Ph.D. candidate at the School of Biomedical Engineering, Konkuk University. His current research interests include human modeling and functional electrical stimulation.

functional electrical stimulation.



James Lee received the B.S. degree in 1994 in Polymer Engineering, and the M.S. degree in 1997 in Computer Engineering from Inha University. He has previously worked at Daewoo Telecom in Korea, Telcordia in USA as a Senior Engineer, Panasonic in the USA as a Leading Engineer, and a S/W Manager at Airwalk Communications,

Inc., USA. Currently, he is a Technical Leader in Mavenir Systems, Dallas, Texas in the USA. His research interests include the protocol design for wireless and wired communication.



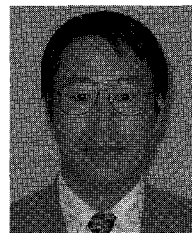
Norio Furuse received the B.E. in 1990 and M.E. degree in 1992 in Electrical and Electronic Engineering from Toyohashi University of Technology, and the Ph.D. degree in 1999 in Electronic Engineering from Tohoku University, Japan. Since 2000, he has been an Associate Professor at the Miyagi National College of

Technology. His research interests include sensory information during walking and neuromuscular control by using functional electrical stimulation.



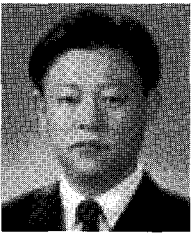
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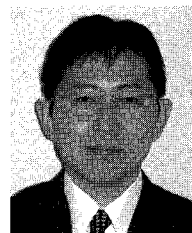
Ryoko Futami received the B.E., M.E., and Ph.D. degrees in Electronic Engineering from Tohoku University, Japan, in 1980, 1982, and 1987, respectively. From 1982 to 1988, he had been a Research Associate at Hokkaido University, Japan. He is currently a Professor in the Department of Human Support Systems at

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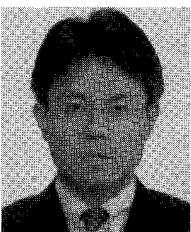
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