Development of Visual-feedback Training Contents for Rehabilitation of Motor Function on the Limbs

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Summary
In this paper, we analyzed the characteristics of muscles and balance to develop integrated contents for rehabilitation of the motor functions with the aged and the infirm, and, on this ground, made prototypical devices and rehabilitation training contents corresponding to each exercise. In the system, rehabilitation training for the upper limbs has a functional form of motion designed to put one's hand on the ball-shaped device and move on the flat table, and that for the lower limbs has motion that moves with physical weight in a standing position on the balance board. To confirm the effects of rehabilitation training, we used EMG to quantify the degree of changes in muscles of the lower limbs, such as tibialis anterior, gastrocnemius, rectus femoris, and biceps femoris, according to balance of the human body. Using the results of this experimental training, we provided several contents necessary for rehabilitation training of the upper and lower limbs.

Key words:
Rehabilitation, Limbs, Visual-feedback, EMG, Balance

1. Introduction

Motor dysfunction of the upper and lower limbs in the body is found to be due to various factors, such as musculoskeletal damage as a kind of immediate external injury, damage to motor functions according to the position of a brain lesion in stroke, or damage to the nervous system maintaining and controlling many kinds of information, including balance, muscular strength, and agility, and is getting more attention because of the increase in the aged population and the high rate of falls [1].

For musculoskeletal damage, repetitive rehabilitation exercise using electric stimulation or assistive tools limited to the muscular conditions in which basic motions are permitted is recommended as an alternative to prevent muscular deterioration after operation or therapy in relation to a patient's standing-up or normal walking especially in case of the damage to the lower limbs, where training inducing spontaneous motivation in a form of delight is a positive help to the patient [2].

The use of feedback during training is important since repetitive motor learning of stimulation leads to reconstruction of the neural circuits in the cerebellum during therapy and learning after brain injury, and for stroke patients, it needs to be made in consideration of low functional recovery due to acute depression that can suddenly occur without history of specific mental disorders following stroke [3].

Many different types of feedback can be used to affect neural reconstruction; among them, various types of contents with gradual properties, such as virtual reality therapy and task-oriented therapy, are being developed as an attempt to induce independent movement performance against a visual stimulus during the feedback process [4-7].

To provide training environment with the introduction of integrated contents which can add feedback to the repetitive training process necessary to recover motor functions of the weakened upper and lower limbs, we developed an integrated motor function training system for the upper and lower limbs by making a rehabilitation device for the upper and lower limbs using an acceleration sensor, testing it for basic movements, and making contents allowing a patient to provide visual-feedback on the basis of the basic movements generated by the use of this device.

2. Methodology

2.1 Target Elements of Rehabilitation

2.1.1 Muscles and Joints

The use of muscles and joints in the upper and lower limbs is a part of the most important point from the perspective of biomechanics; muscular activation is a parameter necessary to recover functions of the upper and lower limbs in rehabilitation exercise [8], where the maintenance and increase of the range of motion due to muscle stretching is essential for natural movement of the body.

2.1.2 Balance

Since the infirm or the aged have more difficulties keeping balance than the non-disabled in everyday living and patients with hemiplegia experience deterioration of their balance, it is essential for them to recover a sense of

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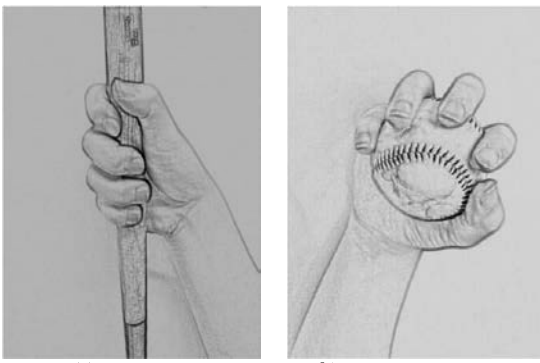
balance of the body. Balance has three properties—steadiness, symmetry, and dynamic stability—and while the balance of the body is associated with posture control, one employs a sensory receptor to use such factors affecting balance control as musculoskeletal and nervous systems, perception of orientation, and motor coordination [9].

2.2 Training Method and Device Development

2.2.1 Training Method Selection for the Upper Limbs



(a) Power grasp (b) Precision grasp

Fig. 1 Two patterns of hand functions in grasp

As methods of handling the training devices for the upper limbs in rehabilitation training for the upper limbs, typical precision grasp suggested by Landsmeer, as shown in Figure 1 (b), was selected.

This method is to place an object between flexor surfaces of the thumb and fingers to finely control muscles of the hand, with fingers semi-flexed and the thumb adducted and abducted to maintain this state; and when a training method of front-rear and right-left movements on the flat table is selected, almost all the muscles for normal fundamental functions of the hands and wrists can be trained, with long extensor of hand for stretching of hands and wrists, long flexor for hand functions in fine exercise, and ulnar flexors and the majority of intrinsic muscles of hand for grip power.

For the use of joints, the wrists shifting the position of fingers and affecting the ability of grip can be trained by radial and ulnar drift as well as by flexion and extension, with the radial and unilateral range of 15° and 30°, respectively, and that of flexion and extension less than 65° and 55°, respectively [10].

2.2.2 Development of Device for the Upper Limbs

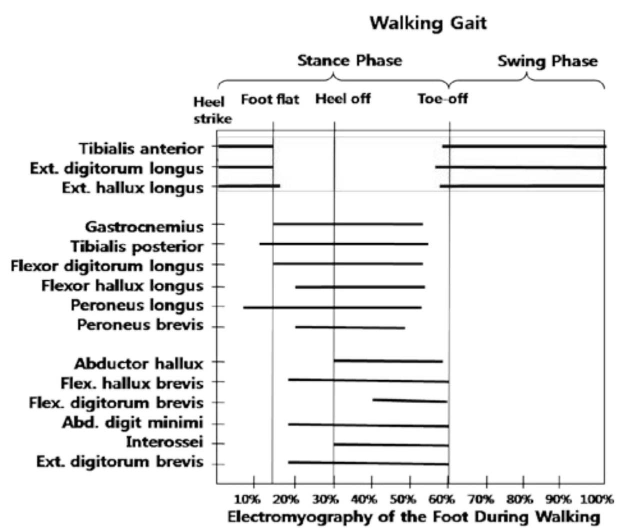
Figure 2 shows the training device for the upper limbs developed for muscle training according to the movement of hands and wrists on the flat table following the selection of the training method for the upper limbs; it has a spherical shape of 50 mm in radius, and can reduce repulsion among patients since it is designed to give a hand a comfortable sense of grip, and can react to even sensitive movement with an acceleration sensor [11].

Fig. 2 Training device for the upper limbs

To prevent the phenomenon of being slipped by sweat possibly caused by exercise with a hand put on the surface of the sphere, anti-slip fiber is stuck to the part touched by the palm and fingers. To allow the hand and the wrist of the patient whose muscular strength of the upper limbs are weakened to rely fully on the device, weight is fixed on a side to set the central point of weight, on which PCB containing an acceleration sensor is horizontally placed.

2.2.3 Training Method Selection for the Lower Limbs

Table 1: EMG of feet in walking



For the training of the lower limbs with the training device for the lower limbs, the exercise of controlling and supporting the body in many directions while standing on the unstable ground was selected with the objective of reinforcing tibialis anterior, which is the most active extensor of the ankle, and tibialis posterior, which is the strongest invertor, during the stance phase of walking, as shown in Table 1, and helping the patient adapt more quickly to load of muscle also essential for walking that most needs the use of the lower limbs.

Since the strength produced by weight and muscular contraction actively serves to stabilize joints, muscles of feet, ankles, and legs coordinate with one another and move irregularly. For ankle training, the range of motion usable in the device is narrower than the marginal range since it is restricted by slope of the balance board parallel to the sole of the foot at 10° and 40° for dorsiflexion and plantarflexion, respectively, as the movement of normal joints; consequently, it is also associated with balance by making one's posture relatively unstable and stimulating relevant abilities to induce self-control repetitively [12].

2.2.4 Development of Device for the Lower Limbs

The lower limb training device can be tilted, with the balance board not rotated, by using 8 rubber bands, as shown in Figure 3, with the objective of cultivating motor coordination and balance as well as activating muscles [13].

Fig. 3 Rehabilitation device for the lower limbs

Since the groove and the hemisphere-shaped implant supporting the balance board are centrally located, it is smoothly tilted in many directions when a user gets onto it, and has an oval form of 540 mm horizontally and 380 vertically in diameter, with the maximum slope of 22° for front and rear and 15° for right and left.

PCB containing the acceleration sensor is stuck within the center of the balance board to catch movement of the board.

2.3 Design of Inner Hardware

As an acceleration sensor stuck to both upper and lower limb rehabilitation devices, the MMA7260QT model manufactured by Freescale is used which can characteristically draw data concerning three axes—X, Y, and Z—identically and use G-select to control the gravity level of the sensor. USB power of 5V was used for the system; and since the acceleration sensor has operation voltage of 2.2V-3.6V, it was designed with voltage of 3V by using voltage reference to meet its operation voltage. The operation simulation flow of the system is shown in Figure 4.

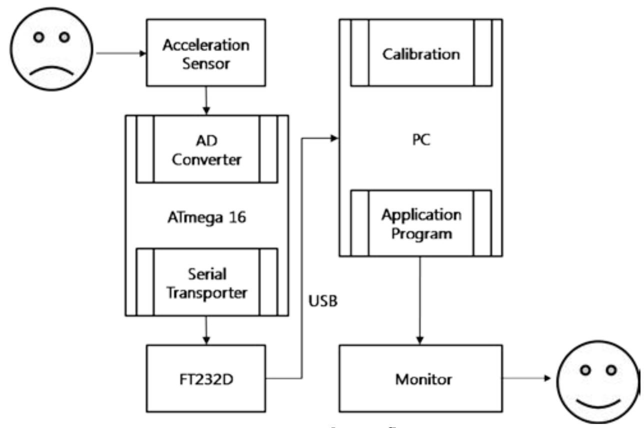


Fig . 4 Simulation flow

When the patient's movement of using the training device is perceived by the acceleration sensor, it generates data concerning each axis; for AD conversion, the timer interrupt function is used to draw an analogue sensor value for the axis at a 1 ms interval to be converted into a digital value. The sensor value from each axis was transmitted to PC via serial communication in the form of user-defined packet, went through the process of analysis, and was used as a value of X and Y axes usable in application programs. The value from the acceleration sensor, which was small, was amplified through OP AMP and had any noise removed by using a low-pass filter.

With the signal, the patient may use the movement of hands in the upper limb training device via the screen of contents produced by the application program and the slope of the body in the lower limb training device in connection with contents.

2.4 Movement Test

The Trigno Wireless EMG System of Delsys was used to test muscular activation against basic movements expressible by the training device with surface EMG; for the upper limb training device, it was impossible to implement the test since movement was made with hands put on the ball less than 1 kg on the flat table, where too weak strength was used, making it difficult to determine muscular activation against movement.

For the lower limb training device, however, it is difficult to easily quantify the use of leg muscles, the size of which continues to change according to the load of dynamic posture on the training device; therefore, the conditions were created for extension and flexion of knee joints, and biceps femoris, rectus femoris, gastrocnemius, and tibialis anterior were selected, as shown in Figure 5, in order to quantify the aspects of their activation using EMG [14].

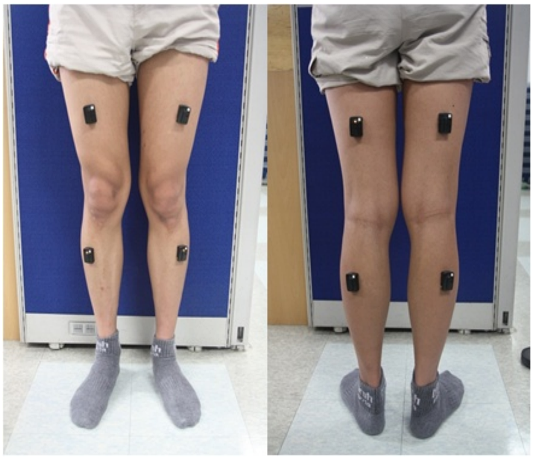


Fig. 5 Muscle selection

The experimental group participating in the movement test consisted of 8 males of 25.6 years (177.3 cm in height and 77.1 kg in weight on the average) and 1 female (158 cm in height and 44 kg in weight), and the EMG signals were quantified in the posture of tilting in the basic right-left and front-rear directions for 3 seconds with a recess of 30 seconds. For data processing following the test, raw signals sampled at 2 kHz went through FFT and, then, were made to pass through the hamming band pass filter set at the range from 10Hz to 500Hz to normalize and make a comparison of the total value of the power spectral density function.

As a result, muscular activation patterns common among 9 participants could be drawn, and they are characterized as follows:

In the flexion conditions of knee joints, opposite tibialis anterior and opposite rectus femoris were highly activated in the right-left direction and no specific activation was found in the front-rear direction, as shown in Figure 6 and 7.

To this contrary, in their flexion conditions, gastrocnemius and tibialis anterior were more activated than other muscles in the front-rear direction, as shown in Figure 8.

The aspects of activation of 8 muscles can be presented as in Figure 9: activation of muscles of the opposite leg tilting in the right-left direction indicates further contraction of leg muscles near the center to control the balance state stably, and backward activation of gastrocnemius and forward activation of tibialis anterior are deeply related to plantarflexion and dorsiflexion at the angle of ankles in extension of knee joints.

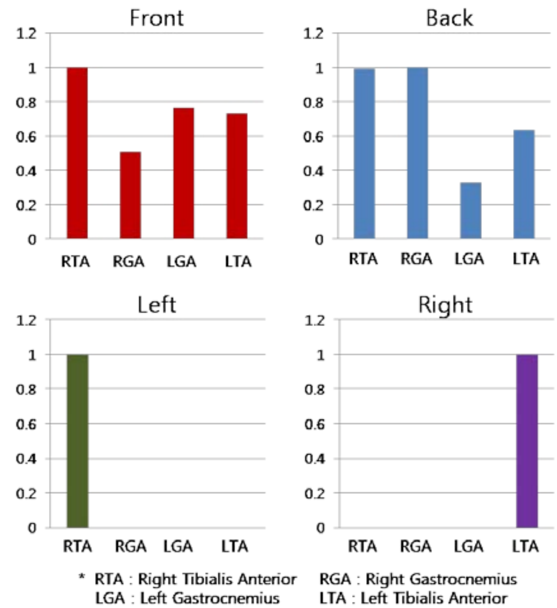


Fig. 6 Activation of lower leg muscles

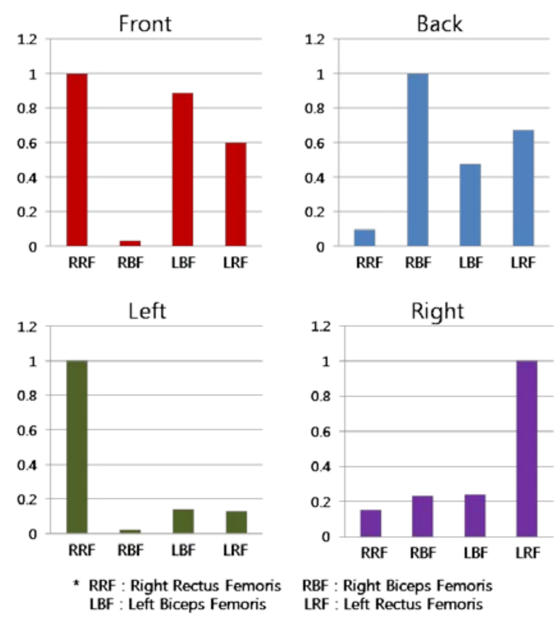


Fig. 7 Thigh muscle activities

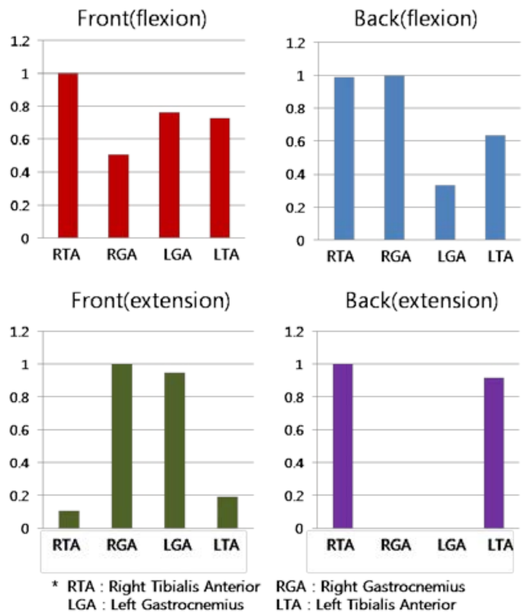


Fig. 8 Activation of lower leg muscles in extension

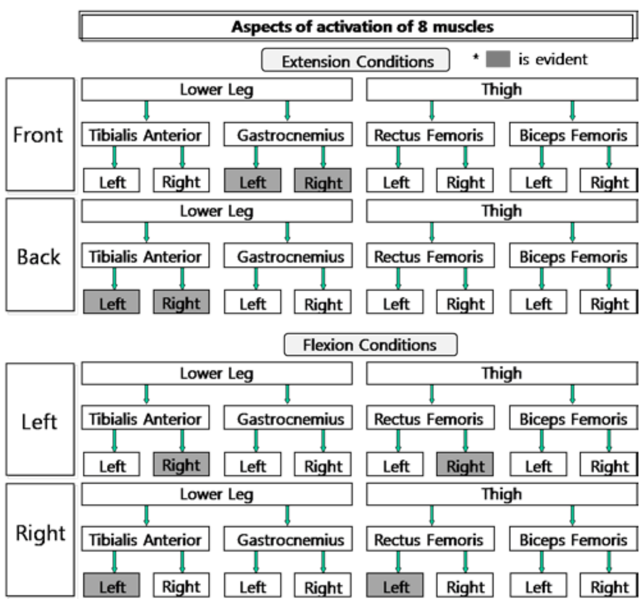


Fig. 9 Aspects of activation of 8 muscles

2.5 Training Contents

We made training contents to cope with movements of the upper and lower limbs in front-rear and right-left directions all on the basis of the effects of muscular activation drawn from the above-mentioned test, and they include a calibration program and the remaining training contents. The participants are first asked to warm up with calibration using a program to put a bead into the hole produced in the up-down and right-left directions, as shown in Figure 10 [15].

Fig. 10 Calibration program

Then, they can carry out up-down contents, right-left contents, Redirection contents as a combination of the two, and Maintain contents specialized to maintain balance and power according to the purpose of training.
Figure 11 shows up-down contents that need to move in the up-down direction so as to prevent the center of pressure (COP) from getting out of the inner line of sine waves moving from left to right.

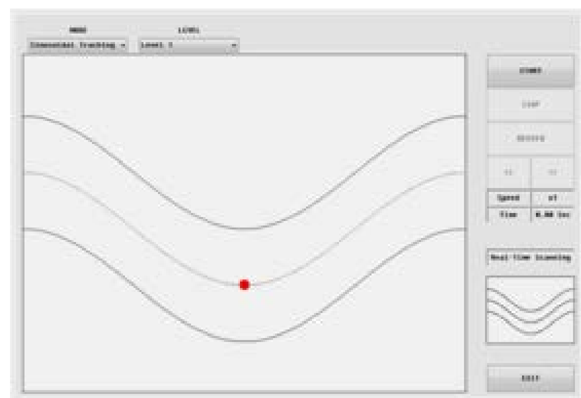


Fig. 11 Up-down contents

When COP of up-down contents is controlled to move in the up-down direction, wrists have upward and downward extension and flexion in the upper limbs; in the normal conditions, 67% of radiocarpal joints and 33% of midcarpal joints are moved in extension, and 60% of midcarpal joints and 40% of radiocarpal joints are moved in flexion, with 3 extensors and 3 flexors possibly involved in the movement. In the lower limbs, ankle joints make plantarflexion and dorsiflexion, possibly causing contraction of gastrocnemius and tibialis anterior.
Figure 12 shows right-left contents that require movement of COP in the right-left direction to place COP inside sine waves moving from up to down.

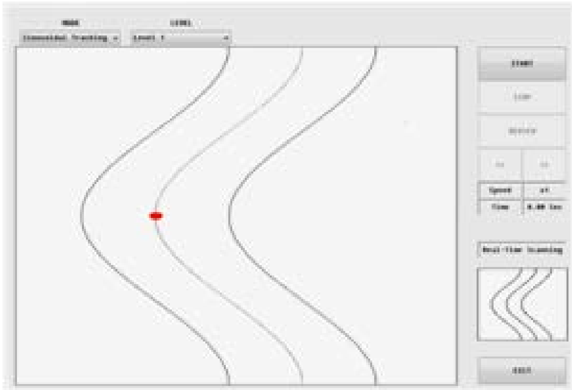


Fig. 12 Right-left contents

When movement is made in the right-left direction in right-left contents, pronation and supination representing axial rotation of hands as inward or outward one occur which can be associated with proximal and distal radioulnar joints and radiocapitella in the upper limbs, and strength of legs spent lifting the body in the opposite direction to the tilting position can be associated with ankle and knee joints in the lower limbs.
Figure 13 shows Redirection contents that require proper control of all the muscles on the basis of each direction shift, with the number of finishing the track within a given period of time as the criterion of achievement.

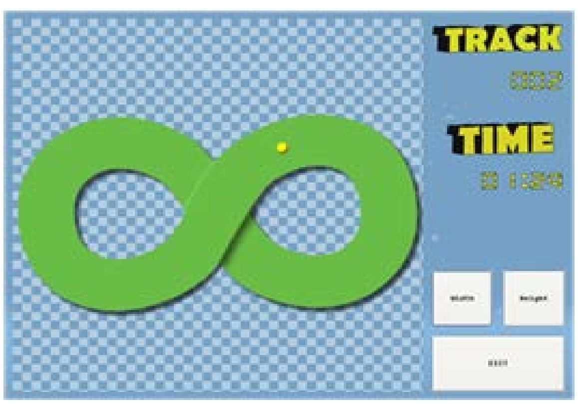


Fig. 13 Redirection contents

To cope with the continuous direct shift of Redirection contents, not only flexion and extension, and pronation and supination but also ulnar and radial drift start to be used in the upper limbs.
Consequently, both sides of extrinsic muscles, muscles of hands, and intrinsic muscles can be associated with movement. In the lower limbs, motor coordination of thigh and lower leg muscles relying on the angle of ankle and knee joints can be associated with it.
Figure 14 shows Maintain contents inducing support of COP within the given area, with the number of succeeding in maintaining posture for a fixed period of time as the criterion of achievement.

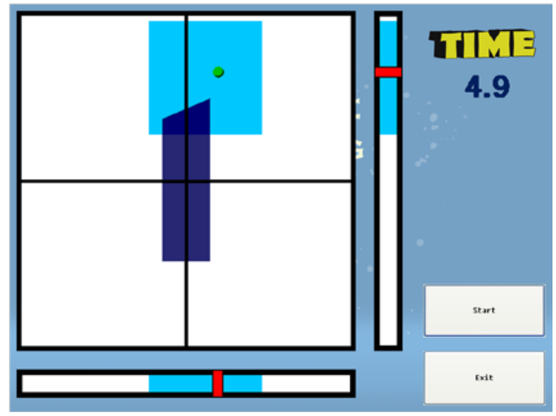


Fig. 14 Maintain contents

Maintain contents need to move COP from the current position to the given one for 3 seconds within each square area randomly given around the center and control and maintain balance and power. Various muscles, a sense of balance, and endurance can be associated with it according to the direction of the task in both upper and lower limbs.

3. Conclusion

To make visual-feedback training contents for motor function training of the upper and lower limbs, we selected training methods based on muscular strength, joints, and balance as key elements necessary for motor function rehabilitation training and made upper and lower limb training devices in consideration of the methods. With test for the upper limbs excluded, we carried out basic movement test for the lower limbs in the process of processing bio-signals using wireless EMG and found that tibialis anterior, gastrocnemius, and biceps femoris and rectus femoris of the thighs had similar activation patterns in front-rear and right-left movements of 9 participants; on this ground, we developed several types of contents to get visio-feedback effects.
Since the experiment generated the result that the muscular activation pattern using the lower limb training device occurred in all of the 9 participants, these visual contents that can be used in front-rear and right-left movements all for upper and lower limb training devices are expected to be useful in the process of motor function rehabilitation training. It should be noted that those issues relevant to complementing stability and reliability will be raised before performing a clinical test in patients and an alternative experiment to confirm the effects of the upper limb training device.

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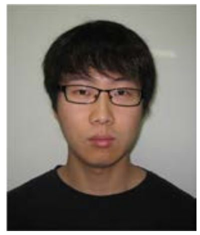

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