

# Sports Training Support Method by Self-Coaching with Humanoid Robot

**S Toyama<sup>1</sup>, F Ikeda<sup>1</sup> and T Yasaka<sup>2</sup>**

<sup>1</sup> National Institute of Technology, Nagaoka College, Niigata, JAPAN

<sup>2</sup> Niigata University, Niigata, JAPAN

E-mail: toyama@nagaoka-ct.ac.jp

**Abstract.** This paper proposes a new training support method called self-coaching with humanoid robots. In the proposed method, two small size inexpensive humanoid robots are used because of their availability. One robot called target robot reproduces motion of a target player and another robot called reference robot reproduces motion of an expert player. The target player can recognize a target technique from the reference robot and his/her inadequate skill from the target robot. Modifying the motion of the target robot as self-coaching, the target player could get advanced cognition. Some experimental results show some possibility as the new training method and some issues of the self-coaching interface program as a future work.

## 1. Introduction

With development of robot technology, concern on Human-Robot Interaction (HRI) increases and many developments for robots acting in various daily environments are performed. For example, reference [1] propose a HRI approach for social robots that attracts and controls the attention of a target person depending on the person's current visual focus of attention. Reference [2] proposes a HRI control approach for a rehabilitation robot driven by a series elastic actuator in order to guarantee the safety of the HRI. Reference [3] proposes a new impedance controller to generate unmatched levels of assistance and task performance during physical HRI, while remaining energetically dissipative. Education fields using robots is also widely taken [4]. In Korea, 700 or more robots are used as teachers for English education [5]. References [6], [7] and [8] introduce a social robotics research and its application at early childhood education or therapy.

Recently, a lot of papers on study of collaboration between sports and engineering have been reported. For example of volleyball that is focused in this paper, references [9], [10] studied the kinematic analysis of volleyball spike jump with motion capture system. References [11], [12] developed a robot system, which play with a human player. However, there are a few trials which use a robot for volleyball training. References [13], [14] designed a new volleyball robot system in order to imitate the world top ranking athletes. Those systems seem to be a unsuitable training method of more basic technique to various players.

This paper proposes a new training support method called self-coaching with humanoid robots. In the proposed training support method, two small size inexpensive humanoid robots are used because of their availability. One robot called the target robot reproduces motion of a target player and another robot called the reference robot reproduces motion of an expert player. The target player can recognize a target technique from the reference robot and his/her inadequate skill from the target robot. Modifying the motion of the target robot, the target player could get advanced cognition as self-coaching. This paper presents the equipments of the self-coaching, an interface program and some experimental results to evaluate the effectiveness or issues for the proposed training support method. As a target technique, this paper treats the forearm pass of volleyball shown in figure 1. This figure shows a lateral view of the



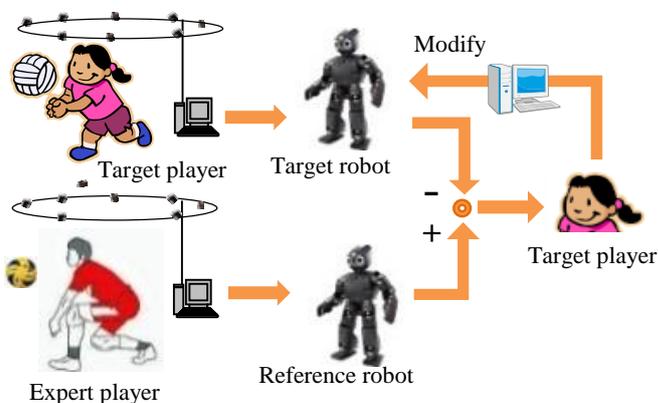
forearm pass, which is an essential technique of volleyball. The volleyball player extends his elbow joints, folds his hands in front of his body and hits the ball against a part of arms from the elbows to the wrists. Because such technique is original with volleyball, and it is not found in other sports, the pass is known as one of difficult sports technique.



**Figure 1.** Forearm pass of volleyball

## 2. Training support method by self-coaching with humanoid robot

Figure 2 shows the outline of the proposed training support method. First, the motions for both of the target player and the expert player are measured by a motion capture system. Based on the captured data, the target robot reproduces the motion of the target player and the reference robot reproduces the motion of the expert player. In sports training, mirrors or video cameras are generally used as reflection devices to know player's skill. The devices are easily available in self-reflection, but there is a problem that blind area exists in the images. The humanoid robots in the proposed method of this paper can enable not only self-reflection without blind area but also self-coaching, since the target player can modify the motion of the target robot for the adequate motion reproduced by the reference robot. The target player could recognize the target technique and his/her inadequate skill.



**Figure 2.** Training support method by self-coaching with humanoid robot

### 2.1. Motion capture system

As the motion capture system of the proposed training method shown in figure 2, this research uses MAC 3D system (nac Image Technology, Inc.) with 8 motion capture cameras shown in figure 3. Those cameras are arranged as shown in figure 4. Table 1 shows the specification of the camera, which detects infrared reflection markers attached to subjects as shown in figure 5. Twenty five infrared reflection markers based on Helen Hayes marker placements [15] are put on body, arms and legs of subjects. The control software of the motion capture system shown in figure 6 performs preliminary processing for analysis such as removing noise or loss of data. With both the position data of 25 markers and the floor reaction forces measured with two force plates, the joint angles, the angular velocities and the joint torques are calculated by a musculoskeletal analysis software (nac Image Technology, Inc., nMotion musculous) using the inverse dynamics with a great detailed human mathematical model as shown in figure 7.



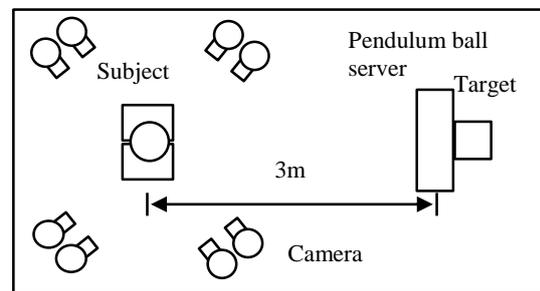
**Figure 3.** Motion capture camera (nac Image Technology, Inc., Osplay)

**Table 1.** Specification of motion capture camera

Resolution	640 × 480 pixel
Pixel number	300,000
Frame rate	1 ~ 250 Hz
Lens length	4 ~ 12 mm

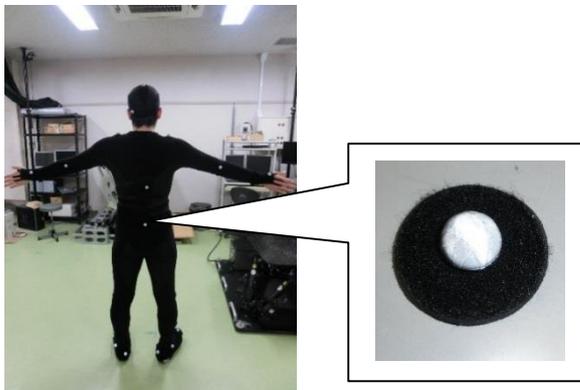


(a) Overview photograph

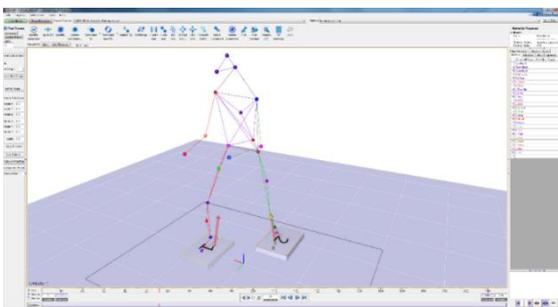


(b) Top view of schematic diagram

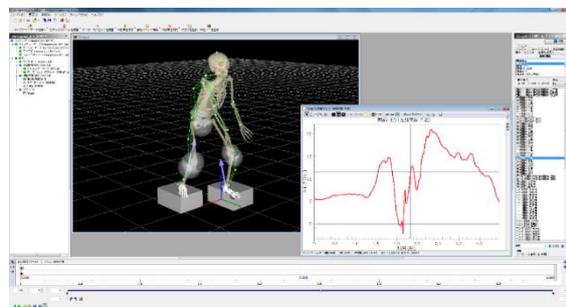
**Figure 4.** Top view of measurement environment



**Figure 5.** Infrared reflection markers for motion capture system



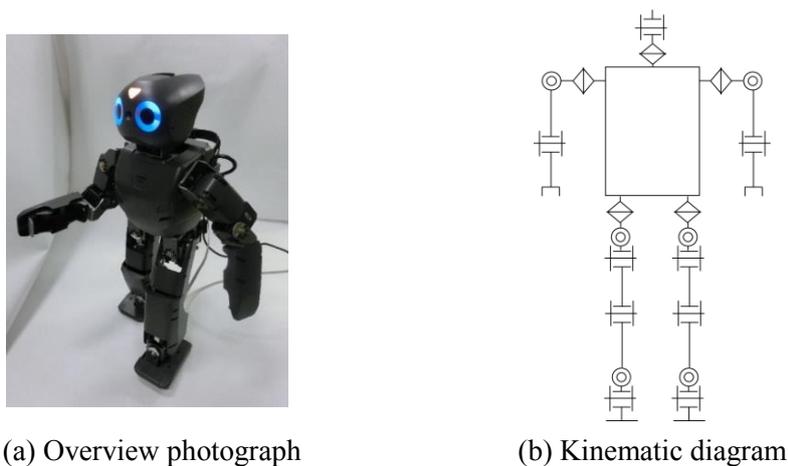
**Figure 6.** Control software of motion capture system (nac Image Technology, Inc., Cortex)



**Figure 7.** Musculoskeletal analysis software (nac Image Technology, Inc., nMotion musculous)

## 2.2. Humanoid robot

DARwIn-OP (ROBOTIS) shown in figure 8 was selected in order to reproduce the motions of forearm pass. This robot has a total of 20 degree of freedom (DOF). The arm has three DOF and the leg has six DOF as shown in figure 8(b). Table 2 shows the specification of DARwIn-OP. Three-axis gyro, three-axis accelerometers, FSR (Force Sensing Resistor) and a built-in PC with 1.6 GHz Intel Atom Z530 on-board 4GB flash SSD are installed in the humanoid robot. The robot has an open-platform for developing or researching, since the hardware structure and the software specification are open. Connecting a keyboard or a mouse to DARwIn-OP through USB interface allows the direct programming, since Linux is installed as the operating system for the built-in PC.



(a) Overview photograph

(b) Kinematic diagram

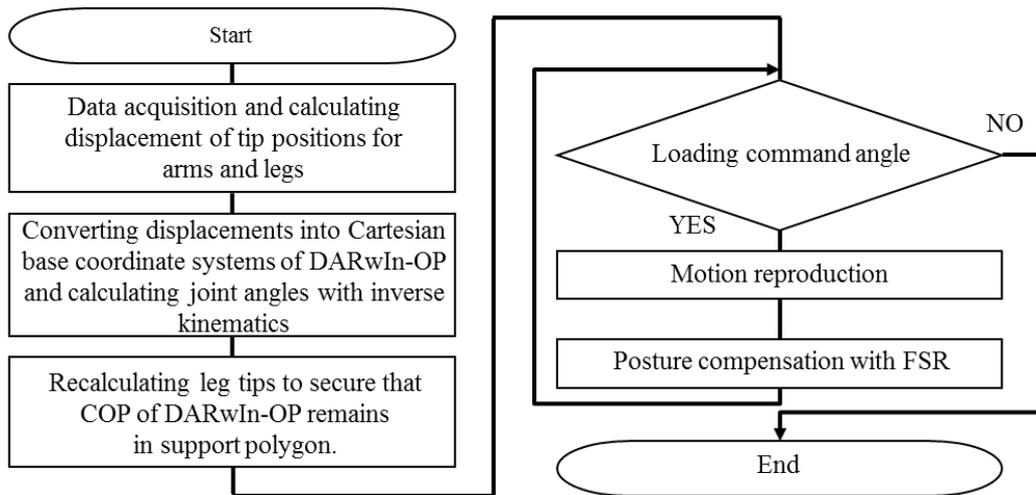
**Figure 8.** Humanoid robot DARwIn-OP

**Table 2.** Specification of DARwIn-OP

Total height	454.5mm
Total weight	2.9kg
Actuator	DYNAMIXEL MX-28T
Degree of freedom	20

## 2.3. Motion reproduction based on inverse kinematics

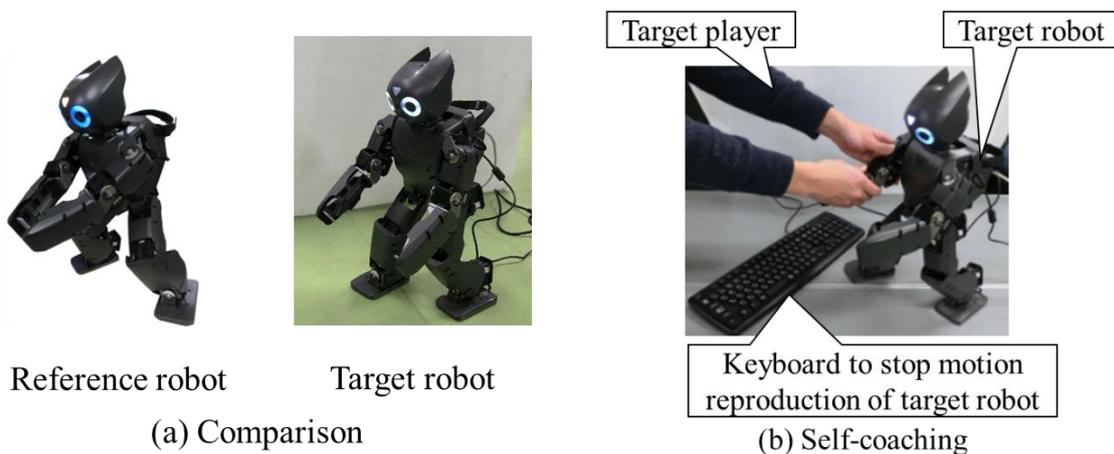
Figure 9 shows the flowchart of the motion reproduction with our considered method. First of all, the motion capture system measures the position data of 25 markers put on the subject and the force plates measure the floor reaction forces for the legs. The musculoskeletal analysis software shown in figure 7 calculates the displacements of each tip position for the arms and the legs. The displacements of each tips are converted into the suited displacements in the Cartesian base coordinate systems of DARwIn-OP. For the forward pose kinematics expression [16], each joint angle for the arms and the legs are calculated with the inverse kinematics. The inverse kinematics problem is solved with Levenberg-Marquardt method known as a robust numerical solution algorithm [17]. Finally, the converted tips of the legs are adjusted so that COP (Center Of Pressure) for DARwIn-OP remains in the support polygon. After CSV (Comma-Separated Values) files of the twenty motor angles corresponding to the target player motion are transferred to each robot, the reference robot reproduces the motion of an expert player and the target robot reproduces the motion of the target player as shown in figure 10 (a). During the motion reproduction, the posture compensation algorithm with FSR works in order to secure the standing stability.



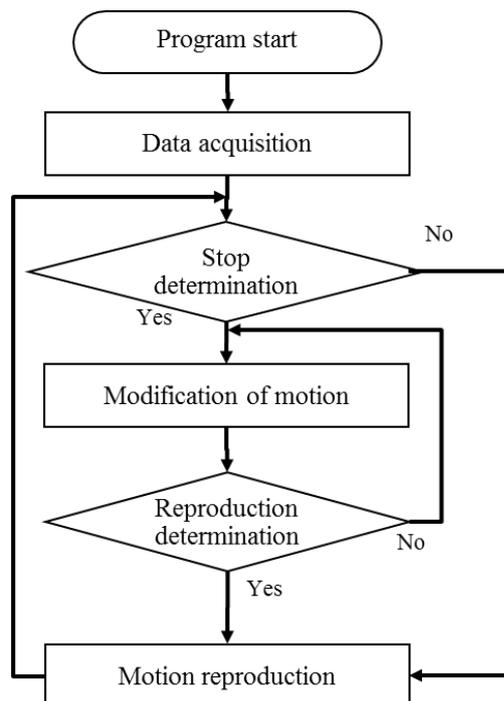
**Figure 9.** Flowchart of motion reproduction based inverse kinematics

*2.4. Self-coaching interface program*

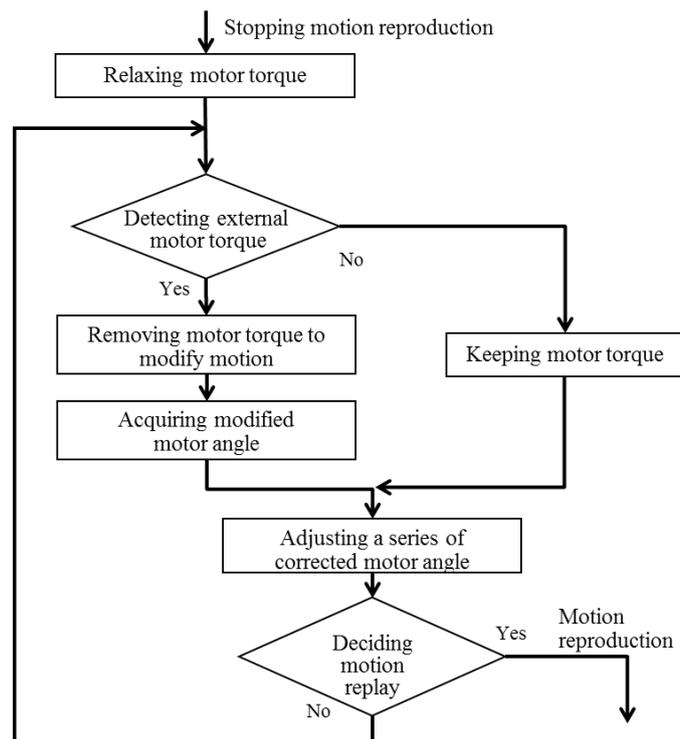
First, the self-coaching interface program, whose flowchart is shown in figure 11 is installed in the target robot. When the program is executed, the twenty motors accept their angle data from the CSV file and the target robot reproduces the target player motion. Similarly, the reference robot reproduces the expert player motion. The target player knows the target technique with the reference robot. Comparing with the reference robot motion, the target player understands the inadequate motion of the target robot as shown in figure 10 (a). During the motion reproduction, the target player can anytime pause the reproduction of the target robot for the motion modification with input on the keyboard, which is connected to the built-in PC with Intel Atom Z530 processor of the target robot, at his/her desired timing. Figure 12 shows the flowchart of the motion modification. With the modification program, the target player can manually modify the motion of the target robot to the reference robot as shown in figure 10 (b). When the target player judges that the modification is suitable, the self-coaching interface program acquires the modified data and reproduces the modified motion again. The modified data is saved in the original CSV file.



**Figure 10.** Self-coaching with humanoid robot DARwIn-OP



**Figure 11.** Flowchart of self-coaching interface program



**Figure 12.** Flowchart of motion modification

### 3. Experiments

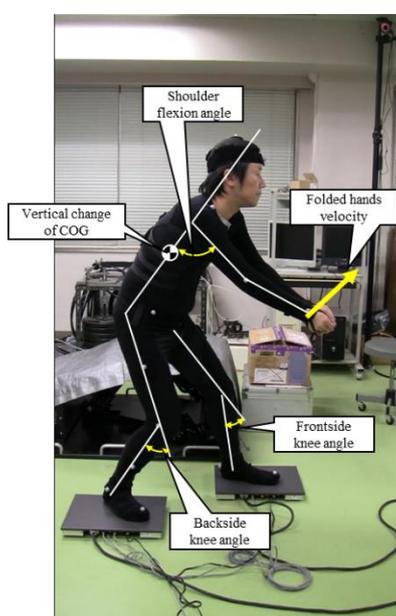
#### 3.1. Target players and measuring their motion

As the target players, the subjects were 14 beginner players of volleyball. They were divided into three groups. Group I is the group to practice without reflection devices, such as mirrors or video cameras. Group II is the group to practice with 3DCG images for their motion as shown in figure 6, and Group III is the group to practice with the proposed self-coaching method. In a period of 10 days, the forearm pass motion of each target player was measured 10 times after 15 minutes practice every day. Added the measurement of 10 times before the 15 minutes practice on the first day, the total measurement times is 110 times in the period. Figure 4 (a) shows the overview photo of our experiments. The target player is surrounded by eight cameras of the motion capture system. A pendulum ball server, which has a pass target at 1.7 m height, is arranged 3 m away from the target player. A series of motion of the target player for a task of hitting the pass target is measured by the motion capture system. Their joint angles, the joint angular velocities, and the center of gravity are calculated by the musculoskeletal analysis software shown in figure 7.

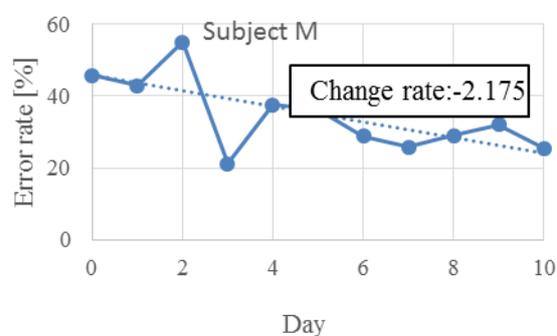
#### 3.2. Evaluation indexes for skill improvement

Although the angle, the angular velocity and the torque for each joint of the subjects can be calculated by the musculoskeletal analysis software shown in figure 7, too much data will make the evaluation of skill complex. Therefore, some simple evaluation indexes only at the moment of hitting the ball are defined. Based on the sports skill classification [18], the evaluation indexes consist of three abilities, such as the positioning, the grading and the reproduction. The positioning means motion ability of body and limbs, the grading means adjustment ability of muscular strength, and the reproduction means reproduce ability of the motion at all the time in a situation. From some common knack points in many coaching books of volleyball. e.g. references [19], [20], the positioning is evaluated from the shoulder

flexion angle, the knee joint angles, the vertical change of the center of gravity at the moment of hitting the ball as shown in figure 13. Similarly, the grading is evaluated from the folded hands velocity at the moment of hitting the ball, and the reproduction is evaluated from the standard deviation of the evaluated items for both the positioning and the grading. The reference values of the evaluation indexes are defined on the basis of the motion data for four expert players of volleyball as shown in the third column of table 3. The skill improvement for the positioning and the grading is evaluated by change of daily error rate to the reference value. As an example, figure 14 shows the skill improvement of one subject for the shoulder flexion angle. The change of the error rate is approximated by the least squares method to a linear function, whose y-intercept is the error rate for the measurement of 10 times before the 15 minutes practice on the first day. The change of daily error rate is defined as the slope of the linear function. The change rate -2.175 means that the error rate can decrease about 20 % for 10 days. The skill improvement for the reproduction is also evaluated by change of daily standard deviation for all daily tests of all subjects per group in order to show a fluctuation of the motion on each day.



**Figure 13.** View point of evaluation indexes



**Figure 14.** An example of evaluating skill improvement

**Table 3.** Target values of evaluation indexes for forearm pass of volleyball

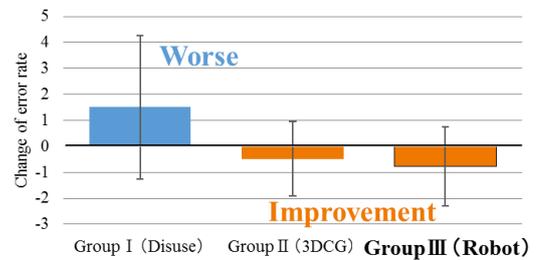
Viewpoint of evaluation	Evaluation variable	Target value
Positioning	Shoulder flexion angle	60.0 [deg]
	Frontside knee joint angle	50.0 [deg]
	Backside knee joint angle	47.5 [deg]
	Vertical change of center of gravity	5 [%] of subject height
Grading	Folded hands velocity	4.5 [m/s]
Reproduction	Reproducibility of positioning and grading	0

3.3. Positioning

Tables 4-7 and figures 15-17 show the evaluation results of the positioning on the joint angles and the center of gravity. From the averages in figure 15, it can be seen that Group II and III can improve the positioning of the shoulder flexion angle, since they could feedback their motion through the 3DCG or the humanoid robot and could realize their inadequate skill. From the standard deviations of figure 15, it can be also seen that Group II and III have smaller standard deviations than Group I. On the other hand, from figure 16, it can be seen that Group III to practice with the proposed self-coaching method could not improve the positioning on the knee joint angles in the lower half of the body. Most of the subjects in Group III struggled to modify the lower motion of the target robot by self-coaching. In the self-coaching, the subjects have to simultaneously modify the hip joint angles, the knee joint angles and the ankle joint angles of the target robot, though they have to modify only the shoulder joint angle for the upper half of target robot. Also, it is difficult to modify the lower half motion to keep the standing stability of the target robot. Figure 17 shows the vertical changes of center of gravity for each Group.

**Table 4.** Change of error rate for shoulder flexion angle

Group I		Group II		Group III	
A	1.988	E	-0.177	J	-1.979
B	-2.436	F	1.468	K	-1.187
C	5.316	G	-1.226	L	2.059
D	1.156	H	-2.757	M	-2.175
		I	0.272	N	-0.639
Ave.	1.506	Ave.	-0.484	Ave.	-0.784
S.D.	2.757	S.D.	1.428	S.D.	1.525



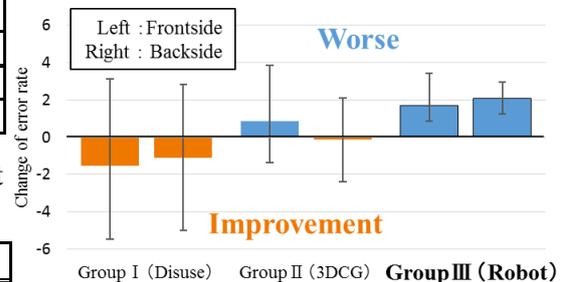
**Figure 15.** Average and standard deviation for shoulder flexion angle

**Table 5.** Change of error rate for frontside knee joint angle

Group I		Group II		Group III	
A	-6.2787	E	-1.0727	J	2.2832
B	1.6536	F	1.1565	K	0.1394
C	4.4008	G	4.4562	L	2.8533
D	-5.9577	H	3.531	M	3.924
		I	-3.757	N	-0.6638
Ave.	-1.546	Ave.	0.863	Ave.	1.707
S.D.	4.676	S.D.	3.007	S.D.	1.711

**Table 6.** Change of error rate for backside knee joint angle

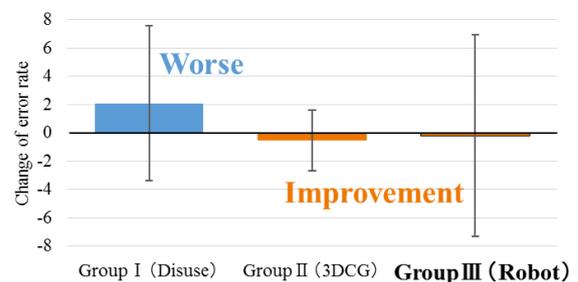
Group I		Group II		Group III	
A	-5.87	E	-1.282	J	3.013
B	0.938	F	0.072	K	2.383
C	4.181	G	4.098	L	1.985
D	-3.639	H	-2.114	M	2.536
		I	-1.4715	N	0.506
Ave.	-1.098	Ave.	-0.140	Ave.	2.085
S.D.	3.913	S.D.	2.235	S.D.	0.855



**Figure 16.** Average and standard deviation for frontside and backside knee joints angle

**Table 7.** Change of error rate for vertical change of center of gravity

Group I		Group II		Group III	
A	4.595	E	-4.016	J	11.818
B	-2.041	F	-0.57	K	0.601
C	9.842	G	-1.324	L	1.168
D	-3.972	H	1.181	M	-5.420
		I	2.151	N	-9.089
Ave.	2.106	Ave.	-0.516	Ave.	-0.184
S.D.	5.481	S.D.	2.140	S.D.	7.116



**Figure 17.** Average and standard deviation for vertical movement of center of gravity

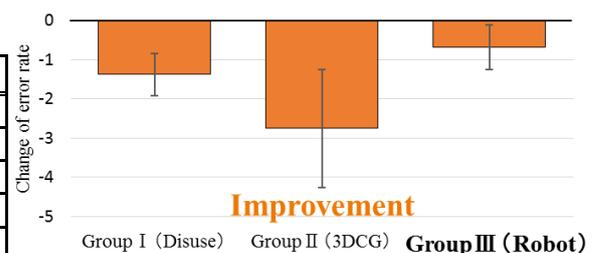
From this figure, it can be seen that Groups II could achieve the best average and the standard deviation of the change rate. It can be also seen that Group III could better average and worse standard deviation of the change rate than Group I, that is, the effect of Group III seems individually different. The reason is because the subjects had shallow understanding of the vertical motion due to the reproducibility, which is reluctantly degraded by smaller size of the humanoid robot than human.

3.4. Grading

As the grading evaluation, table 8 and figure 18 show the folded hands velocity to generate the impulse on the volleyball. From this figure, it can be seen that Group III to practice with the proposed self-coaching has smaller change rate than Group I and II. It is difficult for the subjects to modify a series of the movement with our self-coaching program, since the self-coaching interface program shown in figure 11 allows the target players to modify the target robot motion only at the moment of stop determination from the keyboard. Also, it is hard for the target players to imagine the swing timing, since the proposed method does not show the trace of the volleyball.

**Table 8.** Change of error rate for folded hands velocity

Group I		Group II		Group III	
A	-1.4263	E	-1.4984	J	-1.2068
B	-2.2226	F	-5.4346	K	-0.7561
C	-0.9533	G	-1.2603	L	-0.6638
D	-0.898	H	-3.1771	M	0.3648
		I	-2.3836	N	-1.1877
Ave.	-1.375	Ave.	-2.751	Ave.	-0.690
S.D.	0.531	S.D.	1.504	S.D.	0.571



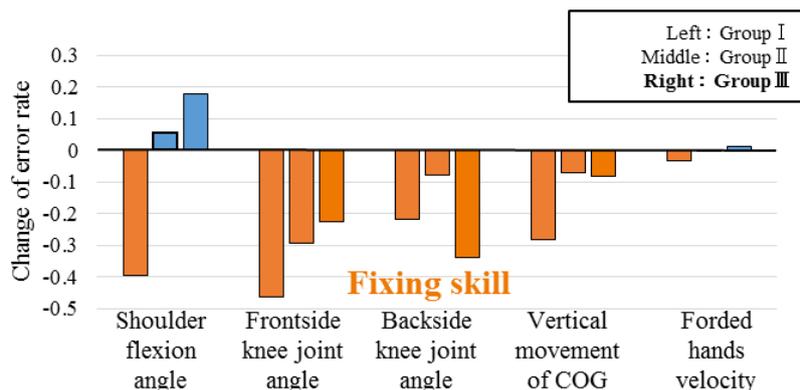
**Figure 18.** Average and standard deviation for folded hands velocity

3.5. Reproduction

Table 9 and figure 19 show the average standard deviation of the positioning and the grading in each group. From this figure, it can be seen that the positioning and the grading for Group I mostly become even. This reason is because Group I had no devices to feedback their motion, such as 3DCG images of Group II or the humanoid robot of Group III. Because they could not imagine the reference motion, they kept their skill with a little improvement. On the other hand, the reproduction of Group II and III varied widely, since they could modified their motion to the reference every day.

**Table 9.** Average of S.D. of evaluation variable

Evaluation variable	Group I	Group II	Group III
Shoulder flexion angle	-0.395	0.051	0.179
Frontside knee joint angle	-0.465	-0.294	-0.226
Backside knee joint angle	-0.218	-0.079	-0.339
Center of gravity	-0.2843	-0.0713	-0.083
Folded hands velocity	-0.035	-0.0044	0.0097

**Figure 19.** Average of standard deviation for positioning and grading

#### 4. Conclusions

This paper proposes a new training support method called a self-coaching with humanoid robots. As the target sports skill, forearm pass of volleyball is considered. From some experimental results, it can be seen that the proposed training method has the fundamental effectiveness for the upper half of human, since the self-coaching for the lower half of the target robot is difficult. Also, the developed self-coaching interface program could not lead the improvement of the grading skill. As a future work, it is necessary to develop procedure modifying a series of motion for the target technique.

#### Acknowledgments

This study was supported by a Grant-in-Aid for challenging Exploratory Research No. 60342507 from the Japan Society for the Promotion of Science (JSPS), for which the authors express their deepest gratitude. Also, the authors would like to express gratitude to the anonymous reviewers for their insightful comments and suggestions to help improve this paper.

#### References

- [1] Das D, Rashed M G, Kobayashi Y and Kuno Y 2015 *IEEE Transactions on Human-Machine Systems*, **45-5** pp664-675
- [2] Haoyong Y, Sunan H, Gong C, Yongping P and Zhao G 2015 *IEEE Transactions on Robotics* **31-5** pp1089-1100
- [3] Bowyer S A, Rodriguez Y and Baena F *IEEE Transactions on Robotics* **31-6** pp1281-1293
- [4] Miyake N and Ishiguro H 2011 *Journal of the Robotics Society of Japan* **29-10** pp2-4
- [5] Shiomi M and Matsumoto Y 2011 *Journal of the Robotics Society of Japan* **29-10** pp867
- [6] Tanaka F, Kozima H, Itakura S and Hiraki K 2010 *Journal of the Robotics Society of Japan* **28-4** pp87-94
- [7] Tanaka F 2011 *Journal of the Robotics Society of Japan* **29-1** pp19-22
- [8] Tanaka F 2013 *Journal of the Robotics Society of Japan* **31-9** pp30-31
- [9] Wagner H Tilp M Serge P V D Muller E 2009 *International Journal of Sports Medicine* **30** pp760-765

- [10] Dunbar N Chemielewski T Tillman S Zheng N Conrad B 2012 *American Society of Biomechanics 36th Annual Meeting* **266**
- [11] Nakai H Taguchi Y Uenohara M Yoshimi T 1988 *Proceedings of the IEEE International Conference on Robotics and Automation Vol.2* pp1083-1089
- [12] Tatsuno K 2000 *Journal of the Robotics Society of Japan* **18-5** pp721-727
- [13] Li Z Jang Y Zhu M Yinjian G 2007 *Proceedings of the 2007 IEEE International Conference on Robotics and Biomimetics* pp1412-1416
- [14] Sun C 2013 *Lecture Notes in Electrical Engineering* **227-5** pp165-171
- [15] Kadaba M P Ramakrishnan H K Wootten M E 1990 *Journal of Orthopaedic Research* **8-3** pp383-392
- [16] Williams R L 2012 *Proceeding of IDETC/CIE 2012 DET2012-70265* pp1-10
- [17] Sugihara T 2011 *Journal of the Robotics Society of Japan* **29-3** pp269-277
- [18] Fukashiro S, Kawamoto R, Ishige Y and Wakayama A 2010 *Science of Sports Motions from a Viewpoint of Biomechanics*, (Tokyo: University of Tokyo Press) Lecture **10-1** pp183
- [19] Selinger A Ackermann-Blount J 1986 *Power Volleyball*, (New York: St. Martin's Press) pp58-60
- [20] Luca J *Pass, Set, Crush*, (Wenatchee: Euclid Northwest Publications) pp20-22