

FULL PAPER

Development and Assessment of a Block Machine
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This study presents a system that consists of three machines to imitate the motion of top volleyball blockers. In a volleyball match, it is essential to improve the hitting percentage of each spiker in order to score by spiking. Iterative spiking training is required for increasing the hitting percentage. Therefore, we develop a block machine system that can be continuously used in an actual practice field for improving attack practice. Each machine is equipped with five degrees of freedom to achieve the required operating speed and mechanical strength. The machine performs high-speed movements on 9,000 mm rails that are arranged parallel to the volleyball net. In addition, an application with a graphical user interface enables a coach to manipulate these machines. It enables the coach to control block motions and change the parameters such as the machines' position and operation timing. We evaluate the feasibility of the proposed block form through practical use of the system in the practice field and confirm that the system has potential for improving attack efficiency.

Keywords: Human-Robot interaction; System design and integration; Ball game sports; Sports training; GUI application

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1. Introduction

In recent years, a variety of approaches that apply diverse engineering techniques have been adopted to improve exercise skills and to win games in the field of sports. Some of these approaches involve the improvement of training methods and schedules [1, 2], development of new equipment [3, 4], improvement of existing equipment [5], tactical analysis, and strategic planning [6]. More and more efforts are being put in to enhance sports training using technology [11, 13–15], particularly in ball game sports. This is because it is difficult to reproduce the same scene and optimize the training level in ball game sports using traditional methods.

In this study, we focus on volleyball and propose a new training system for improving player skills. To improve the ratio of attack effectiveness, which is the most important factor influencing the outcome of a game, it is essential to increase the attack power to reduce the rate of blocked attacks. For this purpose, sophisticated training equipment is required to enrich the practice content of attack training. The equipment should be able to simulate a sufficient block height, limit attack from different directions by multiple players, and present a strategic and organizational block form that is similar to the actual game scenario. Therefore, in this study, we propose a machine that can imitate the block actions of a human blocker, matching the capabilities of the top players in the world, and possess the aforementioned abilities. A machine that can replicate the capabilities and actions of top players can be used by athletes at all skill levels. By applying the optimum level setting based on the practicing players, the machine can adaptively adjust the playing ability. Furthermore, since the exercise partner is a mechanical system, it is possible to practice the same play repeatedly.

In the past, various systems for sports training have been developed. However, machines capable of imitating and reproducing the ability and actions of top players have rarely been seen. Many such systems have not been utilized in actual practice. This is because high operational speeds and mechanical strength are required to imitate the play and actions of top players. Furthermore, the machines must be highly stable and available. In this study, we designed and manufactured a machine for the sole purpose of block actions to replicate the various forms as quickly as top players by limiting the machine's degrees of freedom (Figure 1). As this makes it possible to construct a realistic environment, we can propose a system that can interact with body movement. In addition, we developed an application that can easily and flexibly operate the system, which is composed of three machines. Furthermore, we analyzed the block motion of top athletes using a national team's game video and compared the machine to the top athlete to verify the reproducibility of a top athlete's playing and movement abilities. We also verified the effect of putting the system in actual practice.

2. Related Work

In ball game sports, including volleyball, it is necessary to select the best play within an instant even while considering the various dynamic changes that occur during the game. The concrete and practical acts of individual players form what is called a personal strategy, and its achievability is defined with respect to (a) technical capabilities (technical elements) and (b) tactical thinking (perception and recognition elements) [7]. For an attack scenario in volleyball, attack accuracy, attack height, the speed of the ball, and the proficiency of the operation are equivalent to technical capabilities. An assessment of the situation, for example, to gauge the direction in which the opposite team's player aims to attack, to predict if a player aims to attack for a block out, or to recognize the block form and position of the opponent's receiver depending on the way the ball is tossed by the setter defines tactical thinking.



Figure 1. Block machine for volleyball attack training.

It is possible to acquire technical capabilities by performing repeated practice in individual training involving only one person or a small group of people. Commercially available training equipment such as a pitching machine in baseball [8] or a serve machine in table tennis [9] and volleyball [10] are utilized in this manner. The basic mechanism of these machines is a method of discharging balls by frictional force while clamping the ball with opposing rollers. Since these machines can intermittently release a high-speed ball or a breaking ball similar to a ball released by top players by changing their settings, they are ideal for repeated practice. A prototype machine that releases a badminton shuttle has been developed in recent years [11].

In contrast, because tactical thinking always requires the presence of a practice partner, such training opportunities are often limited and the reproducibility of the same situation is low. Despite the high need for training equipment for acquiring tactical thinking in the actual field, such equipment has not been developed. In recent years, however, this need has attracted interest, and it has become a key research topic. For example, Kawamura et al. proposed a curling practice system that can match practice with humans [12]. This system is composed of a machine that can throw the stone and a strategy simulator. However, it is not a practical system for the volleyball training because the locations at which the machine can be fixed are limited and each throw takes a long time. Stoev et al. developed a badminton-playing robot that could detect the position of the badminton shuttle and predict its trajectory in real time [13]. Additionally, it could hit the shuttle back to the opponent. However, since the degrees of freedom are limited in the prototype stage, it is not a practical system for volleyball training.

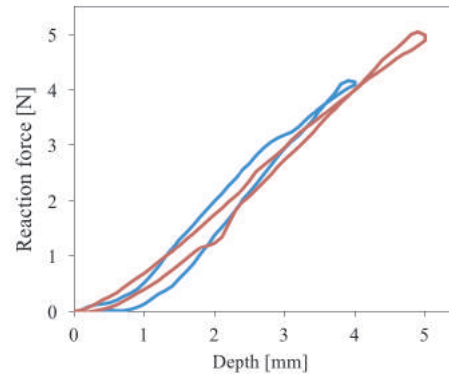
Many other methods for practicing situation assessment have been proposed, such as a system that displays an actual game scene and situation using a head mounted display or immersive projection display using computer graphics [14–17]. However, these methods have the problem that there is no interactivity with a real body (such as a ball or an opponent) and there are differences in the perception of the image from the real world. Furthermore, although a system incorporating game elements using screens for handball shooting training support has been proposed, players can still perceive a difference from the actual game environment [18].

A few systems that use haptic feedback for presenting a force and haptic sensation while smashing in badminton or tennis have also been proposed [19, 20]. However, it is still not in use for sports training systems.

For volleyball, a wide range of studies have been conducted including a biomechanics approach [21] that presents a three-dimensional motion analysis and electromyography measurement at the time of the attack, a tactical study [22] and a study on image processing for data analysis [23]. However, there is currently no training equipment available that can utilize this concept in actual practice based on the body motion of the trainee. Although the aforementioned serving



(a) Photograph of an attacking practice using a block board corresponding to the open attack on the left side.



(b) Comparison of elastic properties of the flexor carpi radialis muscle (red) and polyurethane rubber (blue) conducted using a force gauge.

Figure 2. A block board as a training apparatus

machine is a piece of training equipment that improves the technical receiving capability, there is no training equipment that improves technical capabilities as well as tactical thinking simultaneously.

We developed a block board as a training apparatus to improve technical capabilities in an attack situation (Figure 2(a)). The block board is a static piece of equipment that simulates both arms of a blocker 2 m in height. It is a passive training system without any motors or sensors. It has a manually operated lever mechanism that can change any attitude arbitrarily, such as the height of the jump, forward-bent posture of both shoulders, and abduction and adduction of both arms. Because castors attached to the bottom of this block board enable players to move it easily, three block boards can be positioned independently to reproduce various block forms. Furthermore, urethane rubber, which has elastic properties equivalent to those of human flexor carpi radialis muscle, is used in the arms of the block board. When a human blocker blocks, the ball primarily hits the forearm. Therefore, the elasticity properties of the flexor carpi radialis muscle are measured and urethane rubber having an equivalent elasticity is used. For measurement of the elasticity properties, an elasticity measurement instrument composed of a load cell (LMA-A-5N, Kyowa Electronic Instruments Co.) and a linear motion actuator (ELCM2F10K, ORIENTAL MOTOR Co.) was used. The subject's arm was placed on the tabletop, and the subject was instructed to put the full force on the flexor carpi radialis muscle. The elasticity measuring device was pressed vertically against the carpi radial flexor muscle, and the relationship between the indentation amount and the force was measured (Figure 2(b)). Urethane rubber was adopted because it can be easily processed by modeling to imitate a human arm and because it has a high durability. The human arm-shaped urethane rubber was molded and affixed around the aluminum frame.

A block machine is an extension system of the block board. In the remainder of this study, the system used for driving the operation of each mechanism by a motor is described.

3. System Configuration

3.1 Design Guidelines

The block machine was developed using the following design guidelines:

- (a) Both arms including hands and fingers should be made to simulate the human arm in detail (to be able to reproduce block-out and one-touch actions).
- (b) The motion of the arms at the time of block motion should sufficiently imitate the behavior of a human blocker.
- (c) Three machines which are equivalent in height to humans should move at a position parallel to the net at a high speed.

Block-out means that the attacked ball strikes the side of the blocker arm, and the ball falls outside the opponent's coat, and a point is scored. Therefore, the shape of the machine arm must faithfully reproduce the shape of the human arm. In addition, one-touch means that the attacked ball hits the fingertip of the blocker arm, and the ball falls to the back of the opponent's coat, and another point is scored. Therefore, the shape and impedance characteristics of the machine fingers must faithfully reproduce those of the human fingers.

Since the effectiveness of the block board described in Section 2 was verified through use in an actual practice field, we adopted (a) the same method as that used for the block board, (b) a mechanism that is equivalent to the block board for driving the posture control, and (c) a mechanism in which the three machines moved on rails arranged parallel to the net. To improve the tactical thinking as described in Section 2, it is necessary for the attackers to attack in various directions in response to a situation while recognizing the position information of the opponent, which changes from moment to moment. Therefore, we presumed that this system should have a number of machines that is equivalent to the number of actual blockers. Furthermore, the rail should be located some distance away from the centerline because there is a risk that the attacker could land on the rail after the attack. Therefore, the top of the machine tilts forward to keep its base away from the centerline.

3.2 Hardware Configuration of the Entire System

As the width of the volleyball court is 9,000 mm, the total length of the rail required for the machine to move right and left is 9,000 mm (Figure 3). Three machines are mounted on a common rail, and the entire system is covered with a safety net and a frame to prevent the ball from entering the rail and the players from colliding with the machines, which move at a high speed. To control each component of the machines, a PC, a motor amplifier, and a motor controller are placed into a control box by the side of the rails, and wiring to each machine is supplied through a cableveyor (Figure 4). As the entire system's width is 9,900 mm and depth (except for the portion of upper projection) is 1,200 mm, it does not prevent other players from participating, so it is also possible for players to receive training by playing behind this system. Furthermore, because the distance from the centerline to the rail is 700 mm, the problem described in the design guideline can be avoided. Since this system can be operated only by coaches and players in the practice area, it is necessary to automatically calibrate this system. Therefore, each mechanism is automatically calibrated at system startup by using optical sensors.

3.3 Hardware Configuration of Each Machine System

The appearance of each machine is shown in Figure 5, and its components and mechanisms are described in this section. Since this system requires a minimal configuration for reproducing the actual blocking motion, each machine has five degrees of freedom (movement right and left, jumping, tilting, and abduction and adduction of both arms), just as the block board does. Therefore, the movement of the machine in the front-back direction, the elbow joint, the wrist joint, etc. was limited in this system. Each degree of freedom is driven by an AC servo motor. A single-phase 100 V 400 W motor is used as the driving unit to enable the jump mechanism, the tilting mechanism and abduction and adduction of both arms mechanism. For the drive unit

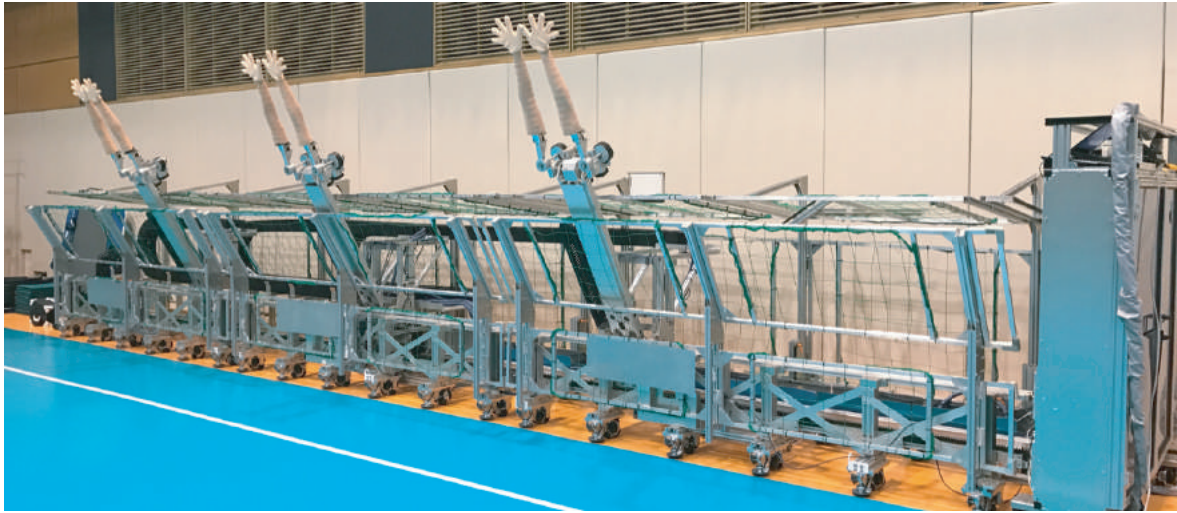


Figure 3. System overview: This photograph shows an initial position and posture of three machines. This is the most typical position relationship before block action in volleyball. The arms of the machine are wound a medical taping tape, and hands and fingers are covered with gloves of skin color.

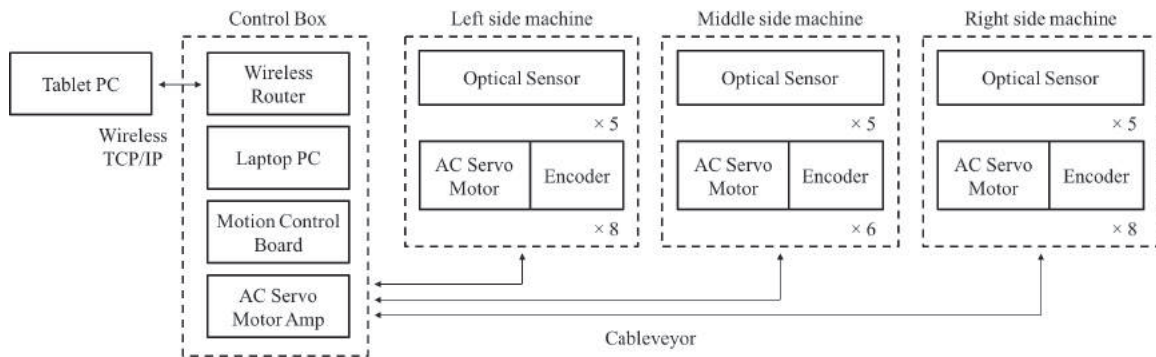


Figure 4. System configuration diagram: Motors and sensors are installed in each machine, and other control equipment is stored in the control box. Cables connecting the control box and each machine are supplied using a cableveyor. The power source, 6 systems of single phase 100 V and 2 systems of 3 phase 200 V, is connected to a switchboard in the control box.

for the right and left movement, two three-phase 200 V 5 kW motors are used for the middle machine and four single-phase 100 V 400 W motors are used for the side machines.

A rack and pinion mechanism is adopted for the right and left movement. A rack gear 9,000 mm in length is placed on the rail and the pinion gear is attached on the machine (Figure 5(d)). A belt mechanism using a cam pulley with a range of motion up to 600 mm in the vertical direction is adopted for the jump motion (Figure 5(b)). To compensate for gravity, a constant force spring is used at the top of the machine. For the tilting motion and abduction and adduction of both arms, a worm gear is used to prevent the machine posture from being disturbed by external forces when an attack ball hits the arms (Figure 5(c)).

An attack hitting test by top players showed that, after the ball strikes the arm of the machine, the speed of the rebound ball is faster in comparison to the human arm. Therefore, a mechanism to convert the moment in the arm around the shoulder joint into the compression of urethane rubber is adopted to reduce the velocity of the rebound ball (Figure 6). This hardness of the rubber was determined to be equal to the inertia of a human arm by empirical trials (hardness: Shore A32).

In addition, the mechanical impedance of the finger and the hand is also very important to faithfully reproduce the block-out and one-touch after the attack. It is necessary to have a

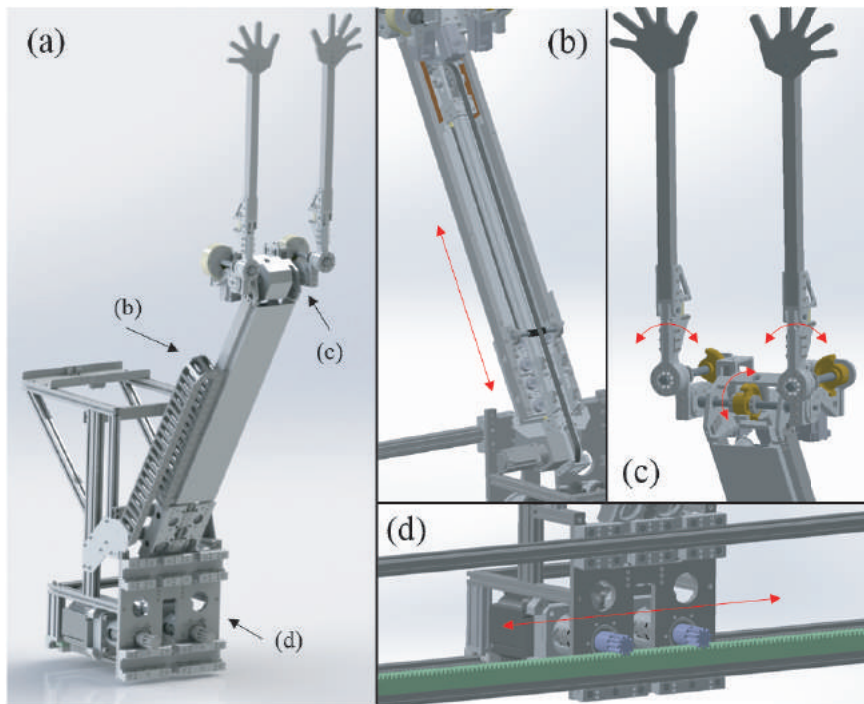


Figure 5. Machine overview: Because the machine's width is 400 mm, every machine is adjacent to each other.

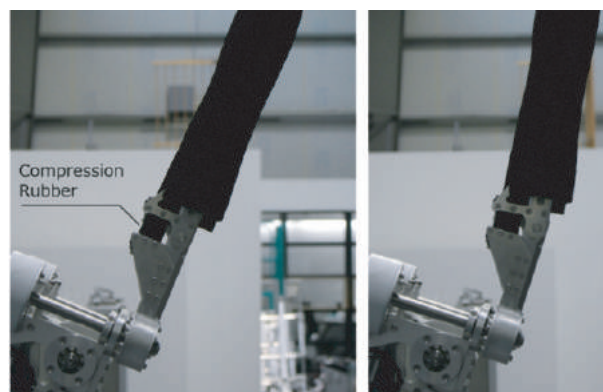


Figure 6. Photograph depicting the shock-absorbing mechanism.

mechanism that is resilient, can deform, and has sufficient strength. Therefore, four 3-mm-thick polycarbonate plates were stacked and fabricated to match the hand shape of the blocker. This makes it possible to reproduce the bending of the fingertip while having enough strength, and therefore it does not break even when the attacked ball hits it.

4. Control Algorithm

The purpose of this system is to establish a training system for the improvement of playing skills in practice. Thus, the machine actions should reflect the practice goals of team leaders and coaches. However, because each machine has five degrees of freedom and the whole system has a total of fifteen degrees of freedom, it is impossible to operate the system manually. Therefore, an operator specifies a block form using a tablet PC, as detailed below, and presets some parameters such as the timing and position of the block in advance. When the control PC receives the operation command, the target time and position of each degree of freedom

in each machine are determined. Subsequently, each motor is trapezoidally driven accordingly using the position control function of AC servo motor. Acceleration/deceleration time and maximum rotation speed of the motor are calculated considering the maximum acceleration of the machine. Hence, three machines automatically perform the block form, and only the start timing of the operation at the time of the toss by the setter is input manually by the operator. The tablet PC used for manual input of the commands by the operator and the control PC on each machine are connected through a wireless LAN. The operation command from the tablet PC is instantaneously transmitted to each control PC with TCP/IP communication. The time lag between the communication by TCP/IP using the manual input by the tablet and the system control PC is approximately 1 ms and the machine starts operation immediately after receiving the communication.

4.1 *Types of Block Form*

A block form in volleyball can be roughly divided into three patterns from the point of view of the attacking side: opening attack, back attack, and quick attack. The opening attack is a principal attack from the right and left sides following a parallel toss and a curved toss by the setters. Hence, the block operation is mainly carried out by one and a half or two blockers. A back attack is an attack that is hit from behind the attack line. Because of its long curved toss, a block operation is mainly carried out by three blockers. In the case of the quick attack, although there are several patterns such as A, B, and C quick attack, it is basically a fast attack that is composed of a short toss and a short run up. Because the time from the toss to the attack is short, the block operation is mainly carried out by one or one and a half blockers.

4.2 *Operation Application*

A graphical user interface (GUI) application for the tablet PC was developed to enable an operator to instruct the system for handling the aforementioned attack patterns. This application enables an operator (e.g., a leader or coach) to operate the system easily and intuitively. Accordingly, it allows the parameters such as the block position, operation timing of each machine, height of the jump, and angle of each arm to be set arbitrarily.

This application performs two main key operations:

- (a) Operations of the block motion in response to the opening attack on the right and left sides
- (b) Operation of the block motion in the vicinity of the center of the net

The characteristics of each function are described below. With respect to (a), it is essential to change detailed parameters such as the antenna-machine distance, machine-machine distance, timing of the block motion, angle of each arm, and the height of the jump. Therefore, the operator sets these parameters in advance (Figure 7) and selects the block form for practice. It is possible to change these parameters during practice (Figure 8). The position of each machine and the height of the jump (0 to 600 mm, resolution 10 mm) can be changed by swiping each head in the GUI. The angle of each arm (-30 to 30 deg, resolution 1 deg) can be changed by swiping each arm in the GUI application. Although the position and height of the machine can be specified every 10 mm, and the angle of arm can be specified every 1 deg, its operation precision is 1 mm, 0.1 deg or less. In addition, since the position does not shift even during repetitive operations, it has sufficient reproducibility.

In contrast, with respect to (b), it is necessary to specify the block position instantly in response to the attack position compared to a specific block form. Therefore, the entire net is displayed in the GUI application (Figure 9) and the operator taps the relative position with respect to the net in response to the attack position. Each machine automatically carries out

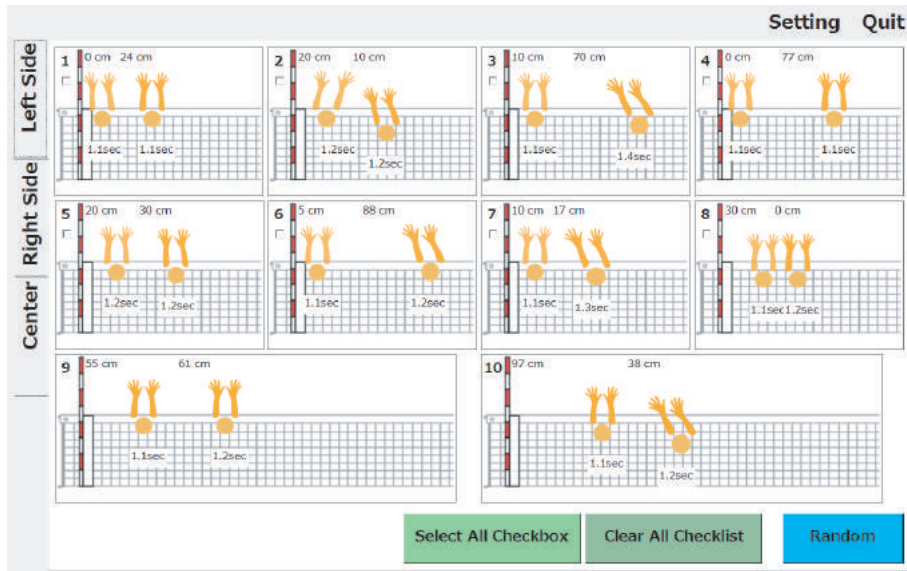


Figure 7. GUI operations of type (a) (Section 4.2) on the left side. An operator selects a block form from the ten patterns on each side.

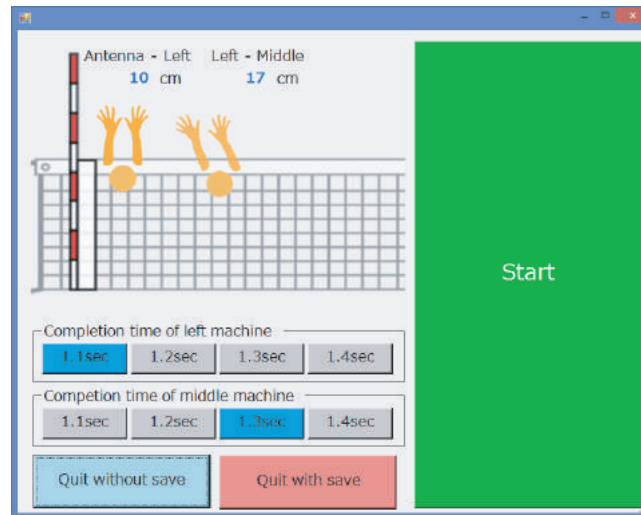


Figure 8. This window appears after an operator selects a pattern as shown in Figure 7. When a green button is pressed, each machine automatically carries out this block operation.

the block operation according to the tapped position. By specifying the number of blocks in advance, the block form is presented in response to the tapped position. In Figure 7, 8, the timing is specified as an interface, but the timing cannot be specified in Figure 9. Although it is possible to impart such functions, the operation leads to significant complexity in practice. However, because the appearance of the hand used for the block is constant, depending on the block position as specified through the command by the tablet, it is possible to change the appearance timing of the block by shifting the timing at which the tablet operator taps.

5. System Evaluation

5.1 Feasibility of the Block Form

As this system is meant to be a practice equipment for improving tactical thinking, it is necessary for each machine to be able to present a block form as quickly as a top player is able to. Therefore, at first, we verified the velocity of the lateral movement during the block. A survey of 18-22-

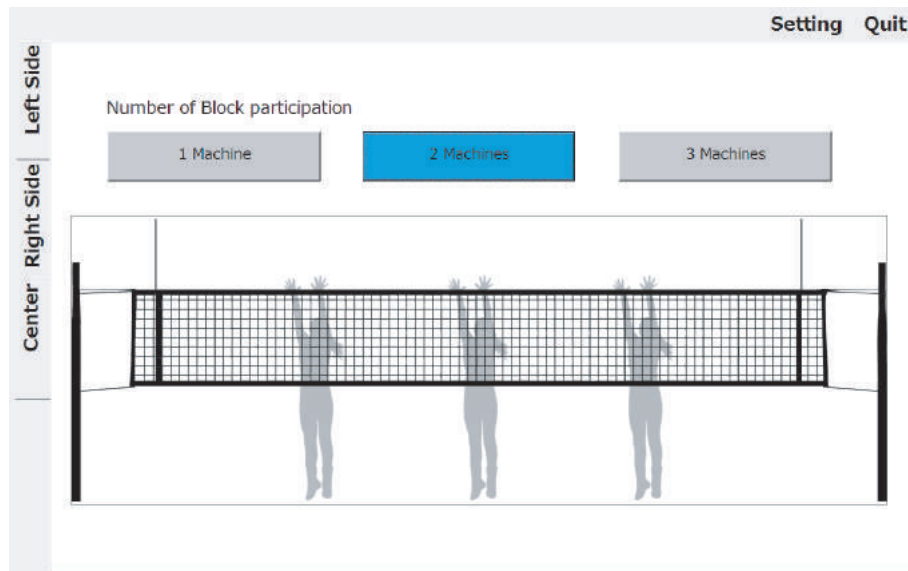


Figure 9. GUI operations of type (b) (Section 4.2). Before tapping an attack position, an operator specifies the number of blocks (1, 2, or 3).

year-old women belonging to a club team from the top National League in the United States found that, after the block motion around the center of the net, the required time to move to a point distance of 3,000 mm was about 1.1 s on average [24]. In contrast, the machine can move 3,700 mm (the maximum range of the middle machine) within 1.1 s. Hence, the machine has a sufficient speed of motion. Because this performance is a target set by an All-Japan women’s volleyball team, by achieving this, we conclude that the system can reproduce the actions of top players.

Next, we analyzed the block motion of the top players and evaluated the machine by comparing it to the machine’s performance. We used two-view images of the World Grand Champions Cup held in 2013 to set a target for the analysis. For the Brazilian team ranked first in the FIVB world ranking at that time, the three-dimensional position of the middle blocker head at parallel toss was estimated from the two images behind the end line. In the system of coordinates, the intersection of the centerline and the sideline (referee side) is the origin, the centerline direction is the x-axis, the upper side is the y-axis, and the direction of the end line on the far side is the z-axis (Figure 10). The head trajectory of the middle blocker obtained from four scenes arbitrarily extracted from the game is shown in Figure 11. It shows the trajectory from the time the setter raises the toss until the landing after the block. An example of a change in the right and left movement from the initial position with respect to the time transition is shown in Figure 12. It shows a comparison with the result of operating the machine with the moving distance of the blocker at that time as the target value. Now, the movement start time of the machine is the time when the trigger signal from the tablet is received and the movement start time of the middle blocker is the moment the ball separates from the hand of the opponent’s setter.

It can be seen from each graph shown in Figure 12 that the time taken for the machine to arrive at the target position is lesser than the top players in all the simulated scenarios. Moreover, at the time of the attack, the machine has a longer moving distance and an almost equivalent movement speed as the top players. In some cases, the speed of the machine is somewhat inferior, but since this happens because the locus of the player’s head, movement of the center of gravity and movement of the head at the start of motion are combined. Therefore, if the position of the center of gravity of the players is compared, it is inferred that the machine will be faster.

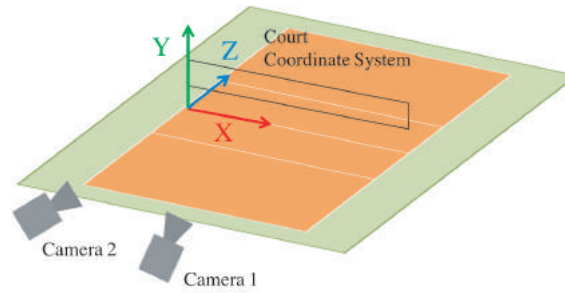


Figure 10. Three-dimensional position estimation from two images behind the court: Conversion from camera coordinate system to court coordinate system.

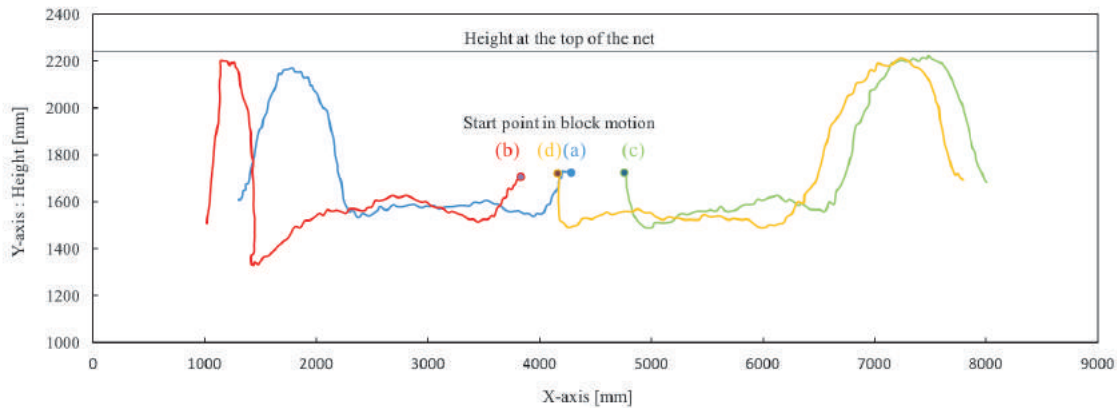


Figure 11. Head trajectory of middle blocker in each block situation during an international game.

Finally, the feasibility of the block form presentation was verified using an actual game image. Although there are various types of block form, the block form that is carried out by the two blockers at the end of the net offers the closest representation and requires the maximum amount of time. A comparison of the block operations by top players in the actual game and a reproduction of a similar operation by our system is shown in Figure 13. Although there are restrictions on the operation because of the limited degrees of freedom, we conclude that our system can generally reproduce the operation. However, by restricting the degree of freedom of the robot, the appearance of the arms from the net becomes faster than the human blocker. The height of the hand position of a human blocker changes according to the change of the position of the center of gravity due to the jump motion and the change of the hand position due to the movement of the flexion of the shoulder joint and the extension of the elbow joint. Although the machine can reproduce the jump motion, the latter motion cannot be simulated, and the robot reproduces the motion using the inner and outer rollers of the shoulder joint. Therefore, though it cannot be said to be an exact replication of the players' action, it does offer an approximately similar motion. By giving motion to the shoulder joint and elbow joint, more accurate motion can be reproduced in the future.

The ability of a machine to move faster than a human blocker indicates that it is possible to reproduce various blocks performed by humans by changing the trajectory tracking. However, the trajectory of the block motion by a human blocker is significantly different for each blocker and for different plays. Although it is possible to indicate the tracking possibility by presenting some sample trajectories, it is insufficient for a machine performance evaluation. Therefore, in this study, comparative evaluation was performed for the highest speed. In the future, it is necessary to illustrate some block patterns and to show their tracking possibility as well.

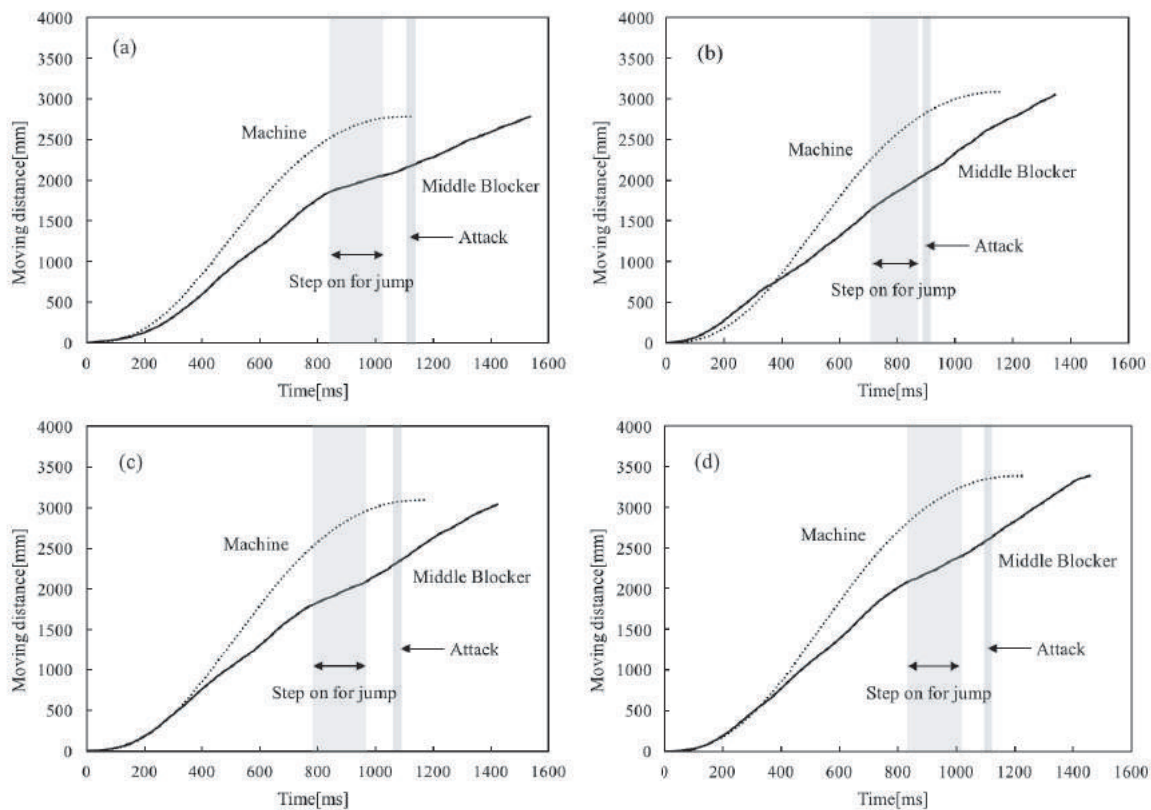


Figure 12. Change in the right and left movement from the initial position with respect to the time transition in each situation represented by (a)-(d) in Figure 11.

5.2 Feedback from Players

Our system was used for a total of eight days in the training camp of All-Japan women's volleyball team. The total usage time was approximately six hours, six players and three coaches attacked our system, and the system was used 1,503 times. The high availability of this system can be proved from this result. The operator tried to avoid the prediction of the machine's movement by the attackers by changing the parameters one by one. We conducted an interview with the players to evaluate our system based in its use over the eight days. The opinions from the first day are labeled (1-x) and those from the fourth day are labeled (2-x).

- (1-a) It was good that I felt like attacking in the game.
- (1-b) I think that there is not much difference between the movement of a human and the machine.
- (1-c) It was good that a variety of block form patterns can be chosen.
- (1-d) The hand of the machine was easier to see than the hand of a human.
- (1-e) I wonder if it is possible to change the position of the block depending on the length of the toss.
- (1-f) I was scared because of the loud sound.
- (2-a) Since I have gotten used to the loud sound, I do not care about it now. Instead, I am getting better at attacking in various directions because I began to attack while firmly looking at the arms of the machine.
- (2-b) I became aware of the block motion.
- (2-c) I feel that it is effective when there is no coach in the practice field.
- (2-d) I know the position of the machine by its sound.
- (2-e) This system is easier to play against than the block of a human.
- (2-f) I feel it is realistic when the operation by the coach matches the timing with the attack.

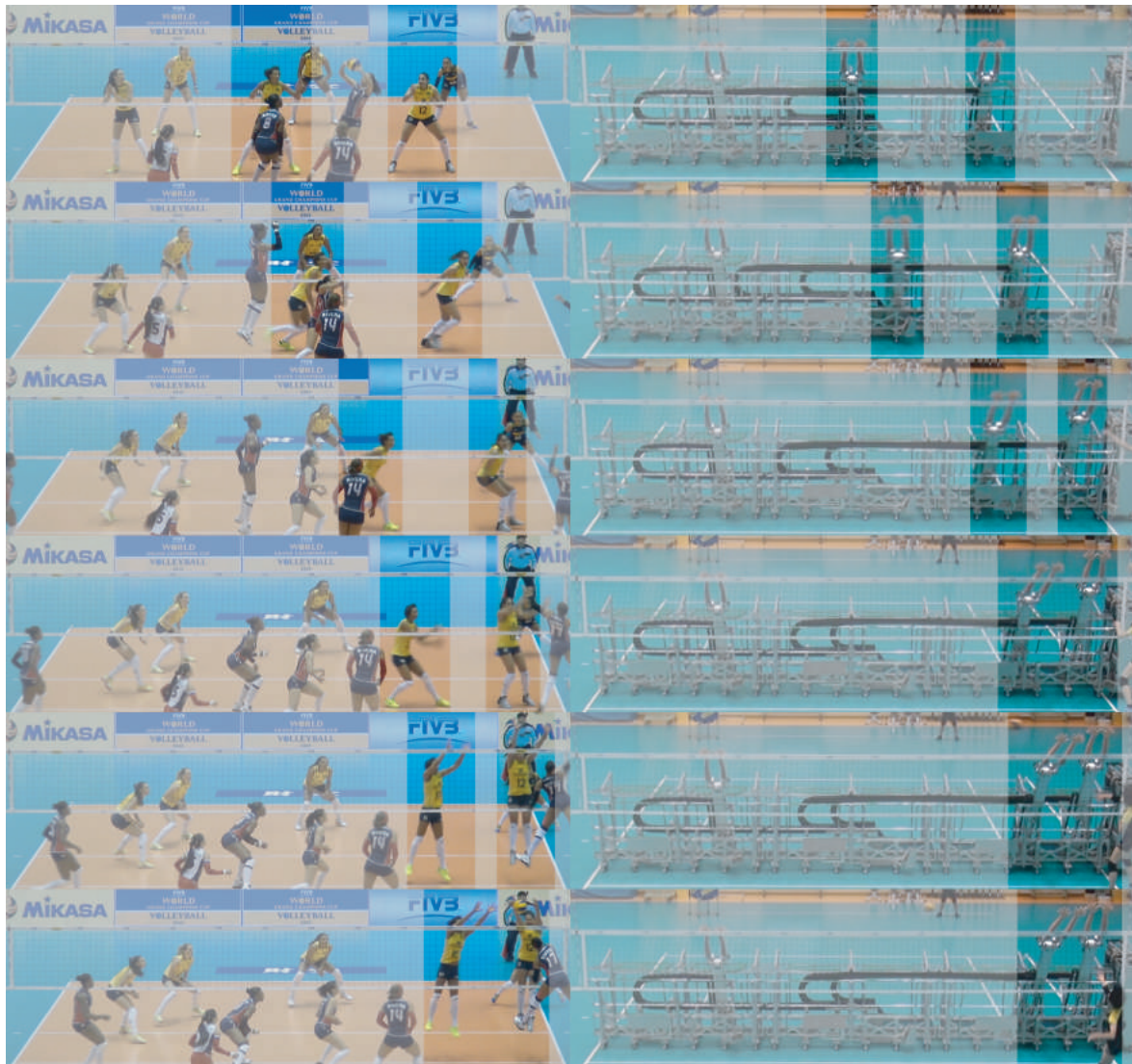


Figure 13. Comparison of a block form presentation between top players in an actual game image and our machines by two blockers at the end of the net. All images are the taken at same time intervals.

Also, the following opinion was expressed from the coaches. When both the position and timing between the attack and the block substantially correspond with each other, the world's top level block is sufficiently reproduced.

As mentioned in (1-b), some players reported that they did not feel a difference between the actions of a human and the machine. As a result, we conclude that the machine can imitate the motion of an actual human blocker without being affected by the limited degrees of freedom. In addition, as observed in (1-c), we can conclude that the various block forms available for the coach, who was the tablet operator, is a key feature of our system. In contrast, (1-d) indicates that the arms of the machine are easier to see than the arms of a human, and a player reported that it is easy to attack from behind our system. It is presumed that there is not much change in the arm posture of the machine because the posture of the arm is upright at 0 deg from the initial posture. Therefore, the arm of the machine is easy to recognize. In the future, the ability to change the initial posture should be incorporated. Furthermore, (1-e) was observed while using GUI operations of type (a) (Section 4.2), and because the block position is set in advance, the operations no longer make sense when a toss is outside the intended position. Even when using type (b) GUI operations (Section 4.2), it was observed that a similar problem occurs because of a displacement of the tap position on the tablet PC. It is necessary to correct the

block position automatically by adding a new sensor system to solve these problems. Meanwhile, conscious changes caused by using our system continuously, represented by the opinions in (2-a) and (2-b) were also suggested.

6. Conclusion

The purpose of this study was to verify if the introduction of a mechanical system that replicates the essence of practice can be an effective method compared to interpersonal practice for sports training. Therefore, in this study, we developed a training system, composed of three machines, that imitates the block operations of volleyball top players. The three-dimensional position estimation of the middle blocker was conducted using an international match video, and the effectiveness of the machine's operation speed was verified by comparing it with the block motion of top volleyball players during actual match scenarios. Since this study showed that the operating speed of the machine is higher than the human blocking speed, it is useful in the following two situations: Firstly, since there is a margin in the operational performance of the system, it is possible to make the arm appear at an appropriate point and timing by adjusting its position following discussions with coaches. Secondly, similar to altitude training in marathon practice, practicing against movements faster than the human body is a useful mode of practice. In addition, our system was continuously available over eight days while intermittently performing high-speed operations and continually receiving the intense attacks of professional players. Therefore, we confirmed the feasibility of the proposed block form and its effectiveness as a potential training system. By addressing the problems exposed during the study in actual practice, in future, our system will mature as a training system to enrich practice thereby improving the ratio of attack effectiveness.

In sports scenarios, there have been few examples of proposing a training system for top athletes. As described in the introduction, quick motion and high availability are important for system construction for top athletes; however, it is difficult to construct a system that satisfies these criteria using existing robotics technologies (humanoid robot, industrial robot arm, etc.). Therefore, the purpose was achieved by limiting the degree of freedom of the robot in this research. We replicated the essence of the block motion of volleyball, focusing on the form of the arms emerging from the net, and assessed its feasibility. As a result, this study is positioned as an engineering contribution as an adaptation/application method of robotics technology and system design theory in sports training.

Since volleyball, the focus of this research, is a net sport, we discussed the applicability of the system to other net-type sports. There are several systems that predict the trajectory of balls and shuttles and hit back to the opponent court in ball games, such as badminton and table tennis [25]; however, there have never been systems that reproduce a play that occurs near a net. For example, there is a possibility of applying the system to replicate the action of a forward player in the doubles format in tennis. It can be applied to construct a system for hitting practice while avoiding the forward player.

As a future task, we intend to establish a technique to modify the block position when the toss is short. A modification of the block form in response to the length of the toss and run up of the players will be achieved by recognizing the position of players and the ball on the court in real time by a sensor mounted on the rail. It will be effective if we can randomly change the machine operation parameters, such as timing of the block motion or angle of each arm; the player will not get used to the movement of the machine. In addition, as a long-term vision, we intend to explore the feasibility of sensing technology, such as a high-speed camera, to recognize the movements of ball and players in real time and construct a method to control the robot's

motion in real time. The block form can be roughly determined by identifying the position of the toss of the setter, the formation of the attacker, and the type of the toss, making the human-like motion control possible.

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