Development of Boccia Robot and Its Throwing Support Interface

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Abstract. Boccia is one of sports designed for the disabled. In boccia, to propel balls to the target, throwing, rolling, kicking and using tools such as a ramp are permitted. Therefore, a wide range of people with or without disabilities can participate in the game. However, at present, boccia games are classified according to the degree of disability. It is difficult that people with severe disability and people without disability participate in the same game together. Therefore, in this study, we propose "RoBoccia", boccia using robotic throwing device that is shared by players and is connectable with various interfaces. We provided the robotic throwing device and an operational interface to operate it. In addition, we developed a throwing support interface using laser pointers to present the estimated lobbing and rolling distances to the operator intuitively. Finally, we verified the usefulness of the developed robot by carrying out the field experiments.

Keywords: Boccia · Sport robot · Throwing · Operational interface

1 Introduction

Boccia, one of the official sports in the Paralympic sports, is paid a lot of attention to because of coming Olympic/Paralympic 2020 [1]. Boccia is a sport created in Europe and designed for people with severe cerebral palsy and people with other severe functional disability [2]. The rule is similar to curling and petanque. The players are divided into two teams (red and blue) and throw or roll their colored balls as close as possible to a target ball. When the end comes, the closest team to the target ball scores.

As a feature of boccia, some throwing methods and assistance of helpers are allowed according to the degree of disability of player. If a player can throw balls by hands even with disability of lower limbs, the player can participate in the game by using a movement aid such as a wheelchair. He or she can also receive assistance of handling balls by a helper during the game as necessary. If it is difficult for a player to use hands, the player can join the game with a helper and kick the ball with feet. In case where it is difficult to use both hands and

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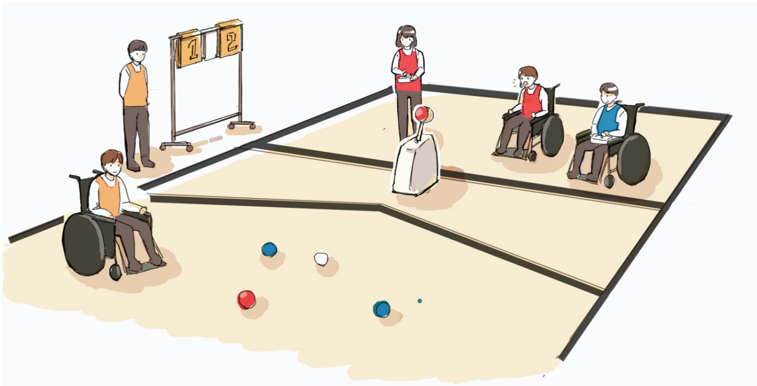

Fig. 1. Concept chart of "RoBoccia", boccia using robotic throwing device that is shared by players and is connectable with various interfaces (Color figure online)

feet, the player can participate in the game by using a ramp. In the case of using a ramp, the player manipulates the ramp by giving instructions to the helper, and rolls the ball with a tool called a head pointer attached to the head. In this way, boccia is a sport that a wide range of disabled people can participate in. In addition, it is attracting attention as a universal sport that not only people with disabilities but also elderly people and children can participate.

On the other hand, boccia games are classified and performed, because of the difference in throwing ability depending on the degree of disability. For example, in throwing with a foot or a ramp, it is impossible to lob balls. As a result, the range of strategies in the game is limited. In addition, it is difficult for the helper to perfectly manipulate the ramp according to the intention of the player. As an effort that a person with disabilities participate in sports, "Cybathlon" has been held [3]. Cybathlon is a sports event where athletes use equipments to which state-of-the-art technology such as robot wheelchairs and powered prosthesis is applied. Also, information and communication technology (ICT) and simulation technology are applied to boccia [4,5]. As project based learning in university, throwing and assisting devices in boccia and bocce, which is said to be the sport that became the origin of the boccia, have been designed [6–8]. However, we cannot find a device that provides enough performance of throwing and rolling to play boccia games so far.

Therefore, in this study, we propose "RoBoccia", boccia using robotic throwing device that is shared by the players and is connectable with various interfaces such as a joystick, a trackball, a foot pedal, a mouth interface and so on, as illustrated in Fig. 1. We developed a throwing robot that acts as an motor organ extending the throwing ability of the player, and that can selectively lob and roll a ball within a court of about 10 m [9,10]. In addition, by providing various operational interfaces for this robot, it is possible to correspond to a wide range of physical conditions. Furthermore, we developed a throwing support interface that presents the estimated lobbing and rolling distances to the operator with

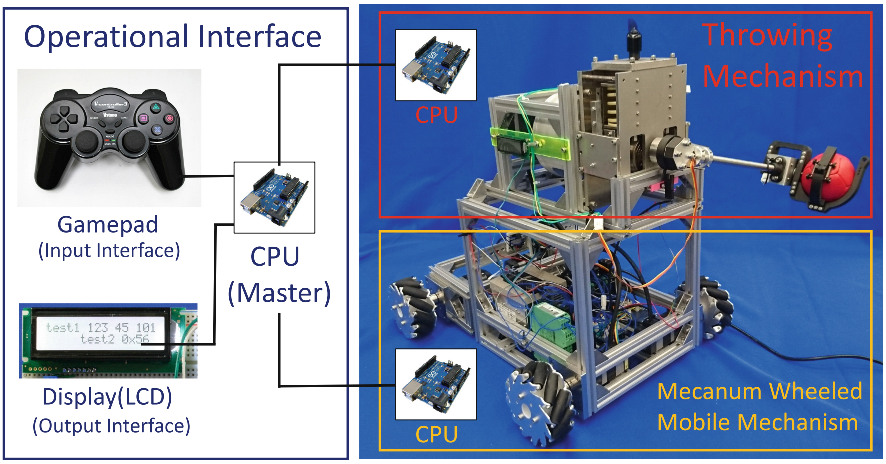

Fig. 2. The developed boccia robot

the laser pointers that are mounted on the robot [11]. By this boccia robot, it is expected that everyone enjoy playing boccia without the classification.

2 Development of Boccia Robot

An overview of the boccia robot developed in this research is shown in Fig. 2. The robot is mainly composed of a throwing mechanism, a mobile mechanism, and an interface unit including controllers. The outline explanation is described in the following section.

2.1 Throwing Mechanism

The developed throwing mechanism is shown in Fig. 3. In this mechanism, a stepping motor with gear and an arm are connected via a clutch. The axis of the arm has an eccentric cam with compression coil springs. After applying an electric power to the clutch, during the rotation of the arm to the initial angle, the eccentric cam compresses the springs. When disconnecting the clutch by turning off, the potential energy stored in the springs is instantaneously released and the arm is swung. The potential energy of the springs can be changed by setting the initial angle of the arm, α, which determines the initial velocity of the ball.

In addition, a hand mechanism shown in Fig. 4 grips the ball by the finger of the one link mechanism with the tension springs before throwing the ball. After the clutch in the throwing mechanism is disconnected, the arm accelerates and the centrifugal force acting on the ball increases. At the certain angle of the arm, the finger comes off and the ball is released from the hand. The angle of

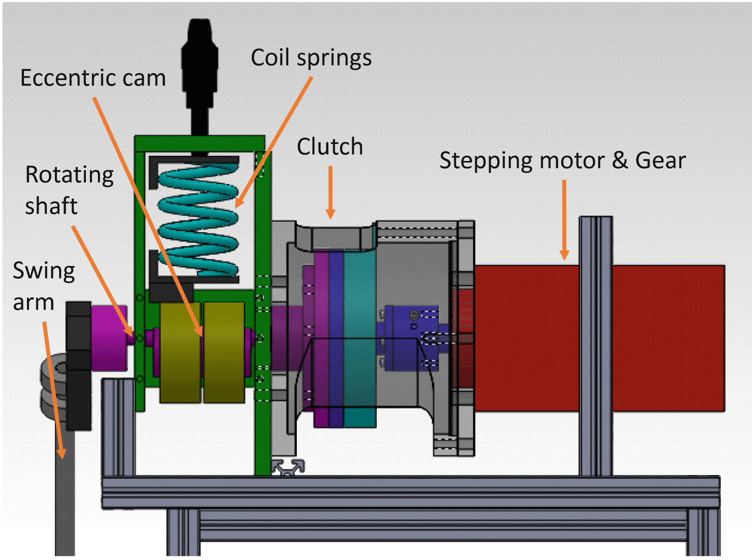

Fig. 3. Throwing mechanism

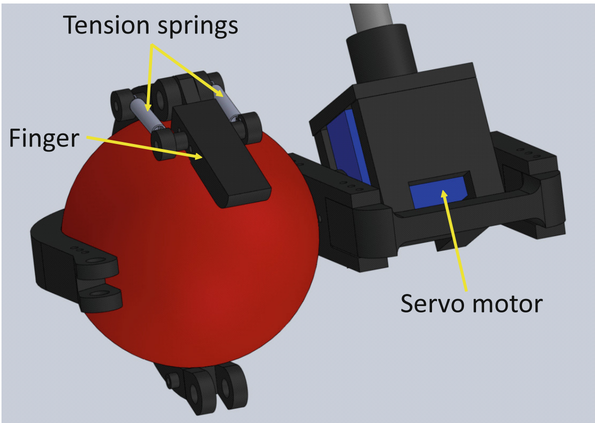

Fig. 4. Hand mechanism

the hand (wrist), β, can be changed by the servo motor shown in Fig. 4, which determines the release timing of the ball or the throwing angle.

In this robot, throwing distance is determined by two parameters of the arm initial angle α and the wrist angle β as described above. Here, the throwing distance is defined as the lobbing distance which is the distance to the landing point of the ball and the rolling distance which is the distance to the stopping point of it. The definition of two throwing parameters α, β, the lobbing distance L and the rolling distance R are illustrated in Fig. 5. Also, the lobbing distance

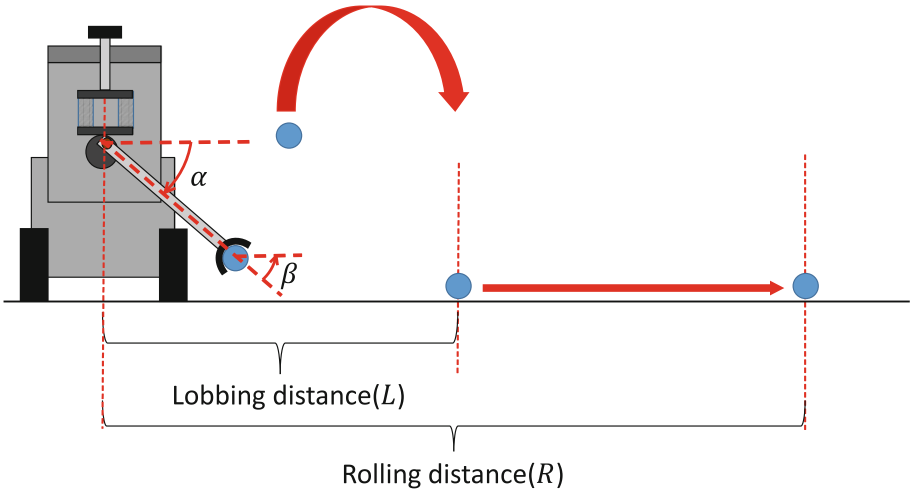

Fig. 5. Definition of throwing parameters α, β & lobbing and rolling distances L, R

and the rolling distance that were experimentally obtained by combinations of throwing parameters α, β are shown in Figs. 6 and 7, respectively.

2.2 Mecanum Wheeled Mobile Mechanism

The robot has an omnidirectional mobile mechanism by the mecanum wheels as shown in Fig. 8. The mecanum wheel is a special wheel in which barrel-shaped free rollers are mounted at an angle of 45° on the wheel circumference. By controlling the rotation of four motors, it is possible to move in all directions without changing the direction of the vehicle body in addition to the same movement as the conventional wheeled vehicle.

In the omnidirectional mobile mechanism using the mecanum wheel, there is no constraint in the direction of movement. Therefore, it is easy to finely adjust the position and orientation of the robot for throwing. The mobile mechanism makes it possible that the robot is transported even by a person with severe disabilities. Furthermore, it also allows the robot to act autonomously in the future.

3 Operational Interface of Boccia Robot

The operational interface has a role of mediator between the operator and the boccia robot. As shown in Fig. 2, the throwing mechanism, the mobile mechanism and the interface unit in the boccia robot each have micro-controllers (Arduino). The micro-controllers communicate sensor information and operational command via I^2C. The controller of the operational interface acts as the

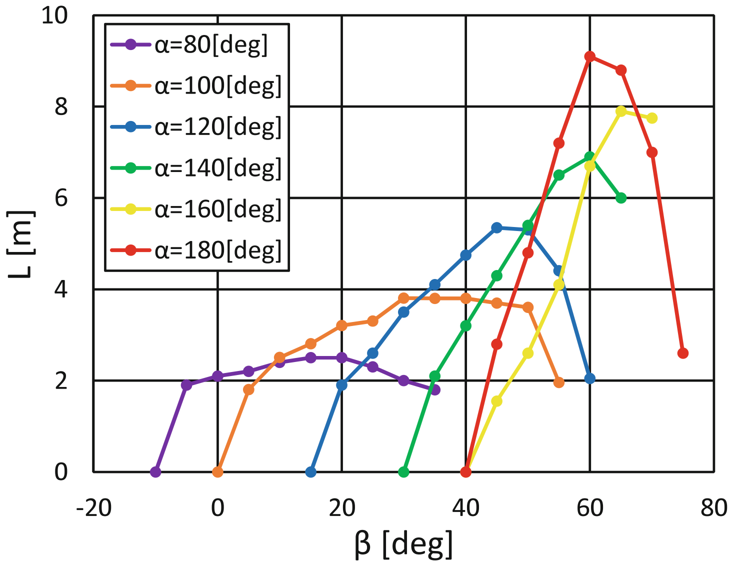

Fig. 6. Lobbing distance depending on α, β

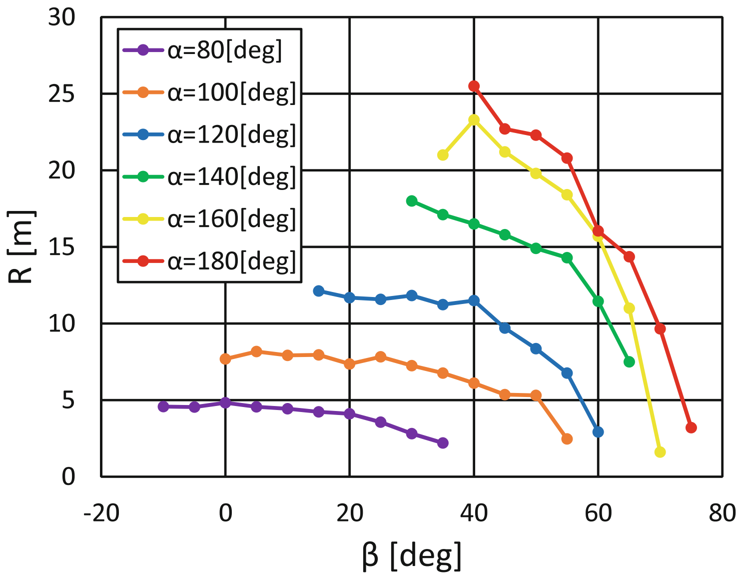

Fig. 7. Rolling distance depending on α, β

master and the others as the slaves. A gamepad (game controller) is implemented as an input interface and a liquid crystal display (LCD) as an output interface. When the operator operates the gamepad, the input to gamepad is

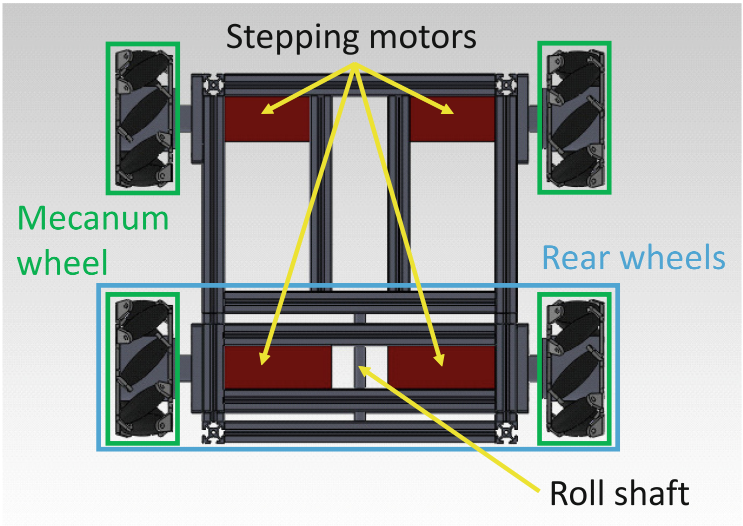

Fig. 8. Mecanum wheeled mobile mechanism

converted into an operational command and the throwing mechanism and the mobile mechanism are controlled by the micro-controllers. On the other hand, when an interface unit receive the information of the robot from the micro-controllers of the throwing mechanism and the mobile mechanism, the value of throwing parameters are presented to the operator with the LCD.

The gamepad used as the input interface is shown in Fig. 9. Firstly, the analog sticks are used for movement. The left analog stick is for omnidirectional movement, and the right analog stick for turning left and right. Next, the arrow pad on left side is used to adjust throwing parameters. The left/right arrow pads are for the arm angle α, and the up/down arrow pads are for the wrist angle β. Lastly, the square pad and the round pad are for switching on/off of the clutch. When the square pad is pressed, the clutch is turned on and the motor and the arm are connected. When the round pad is pressed, the clutch is turned off and the ball is thrown.

4 Throwing Support Interface of Boccia Robot

The boccia robot can throw a ball variously by adjusting two parameters, the arm initial angle α and the wrist angle β. However, it is difficult for the beginner to select the parameters and estimate the throwing trajectory. Therefore, we developed a throwing support system that presents what kind of throwing will be performed according to the set parameters. In this system, the lobbing and rolling distances are presented by projecting the laser pointers to the expected landing point of lob and the expected stopping point of roll based on the calculation from the parameters.

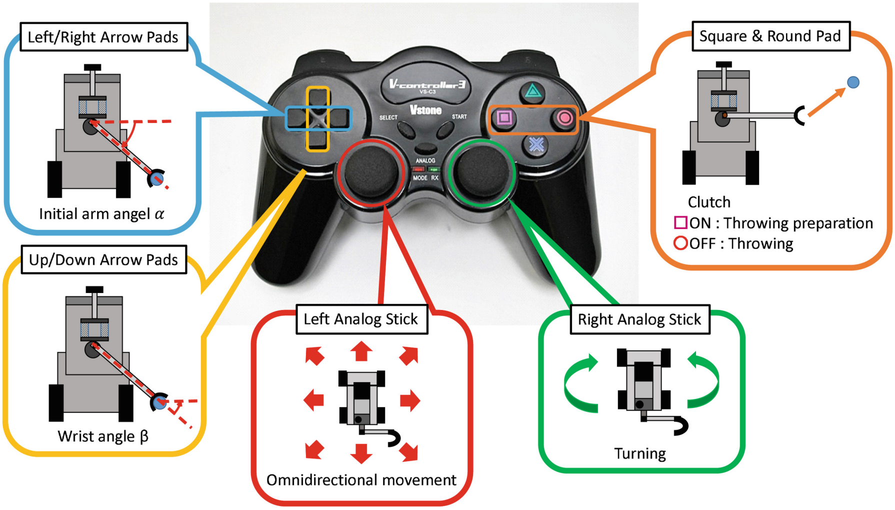

Fig. 9. Input interface of Boccia robot

The arrangement of the throwing support system is shown in Fig. 10. Here, the throwing direction of the ball is along with X-axis. The laser pointer is mounted on the robot at an angle φ as shown on the right side in Fig. 10. Therefore, by controlling the direction of the laser pointer with a servo motor, it is possible to project the laser pointer at an arbitrary point in the throwing direction on X-axis.

The procedure of presentation by laser pointers is described as below. Firstly, the micro-controller of the operational interface receives the values of α and β from the micro-controller of the throwing mechanism. Secondly, the lobbing distance L and the rolling distance R are calculated based on the data previously obtained from experiments. Then, the calculation of the following equations is performed assuming that the angles are $\theta_L = \theta_R = 0$ when the laser pointers point in the direction parallel to X-axis.

$$\theta_L = \arctan \frac{\sqrt{{y_{0L}}^2 + {z_{0L}}^2}}{L - x_{0L}} \tag{1}$$

$$\theta_R = \arctan \frac{\sqrt{{y_{0R}}^2 + {z_{0R}}^2}}{R - x_{0R}} \tag{2}$$

where, θ_L and θ_R are the angles of servo motors for laser pointers of lobbing and rolling distances, respectively. x_{0*}, y_{0*}, z_{0*} represent the offset position of the laser pointer and servo motor shown in Fig. 10.

Finally, the servo motors for lobbing and rolling distances are commanded to rotate to the calculated angles θ_L and θ_R, respectively, and present the estimated landing and stopping points to the operator by turning on the laser pointers.

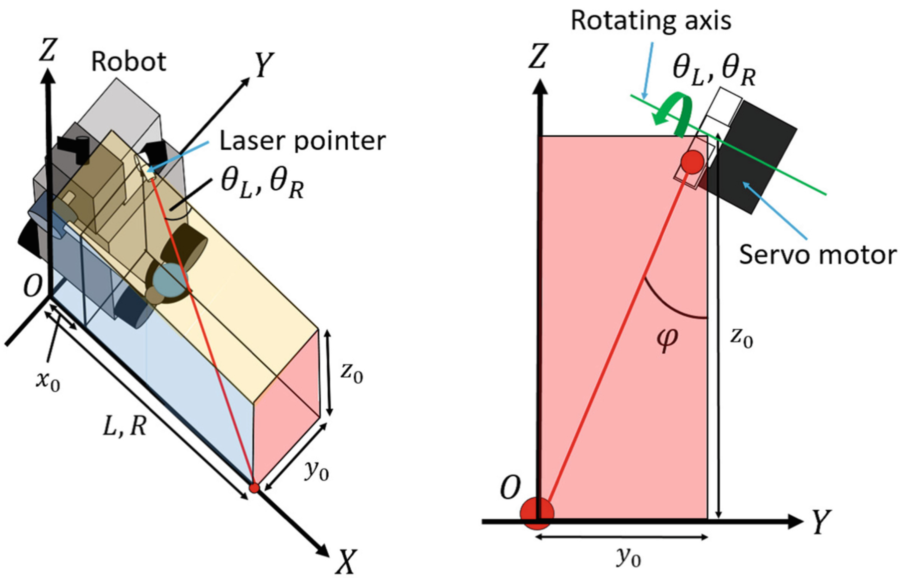

Fig. 10. Arrangement of laser pointers and servo motors

An appearance how the lasers are actually pointed is shown in Fig. 11. Here, the red point represents the lobbing distance, and the green point indicates the rolling distance. The user can intuitively imagine the ball thrown to the target position, because this throwing support interface directly presents throwing distances on the actual court. Also, this system can be used without calibration of coordinates on the court, because the laser pointers are mounted on the robot itself and the coordinates of the robot and laser pointers are fixed.

5 Field Experiments

We conducted the field experiments of the developed boccia robot in the boccia class which was held at Arakawa Campus, Tokyo Metropolitan University. A wide range of people, for example, from beginners to athletes belonging to a Boccia's club team and from young people to senior citizens, participated in this class.

Firstly, we played a game of 6 ends between 3 regular persons in the boccia class (red team) and the robot (blue team) operated by one of the authors as shown in Fig. 12. Three of the red team consist of two persons with disabled leg or foot, who throw balls by hand on their wheelchair, and one healthy person. As a result of the game, the robot team won by 4 red points and 6 blue points. Throughout the game, the robot was rather in the lead. However, there were also scenes where people were in the lead. From this experiment, it was confirmed that the developed boccia robot had sufficient performance to play boccia games because it could play with people who threw by hand in ordinary boccia games.

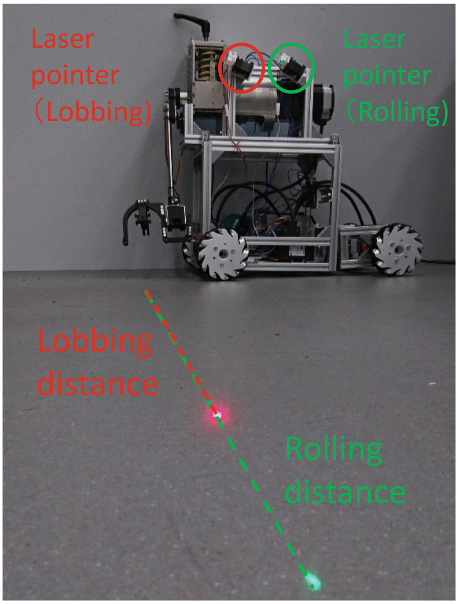

Fig. 11. Throwing support interface that presents lobbing and rolling distances

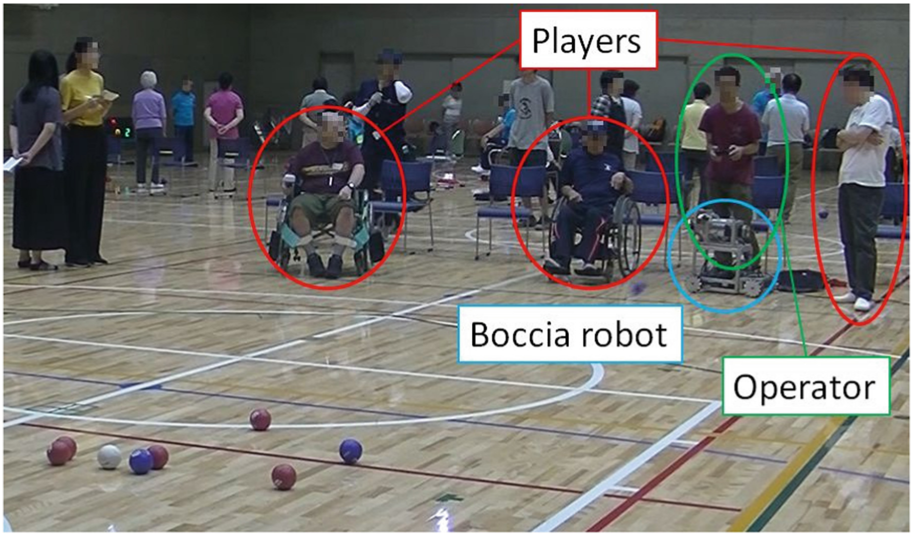

Fig. 12. Game between Boccia robot and people (Color figure online)

Next, we had people who came to the boccia class use the boccia robot as shown in Fig. 13. Also, we conducted a questionnaire survey. As a result of a questionnaire survey, all of people answered "It's fun to try", but nearly half

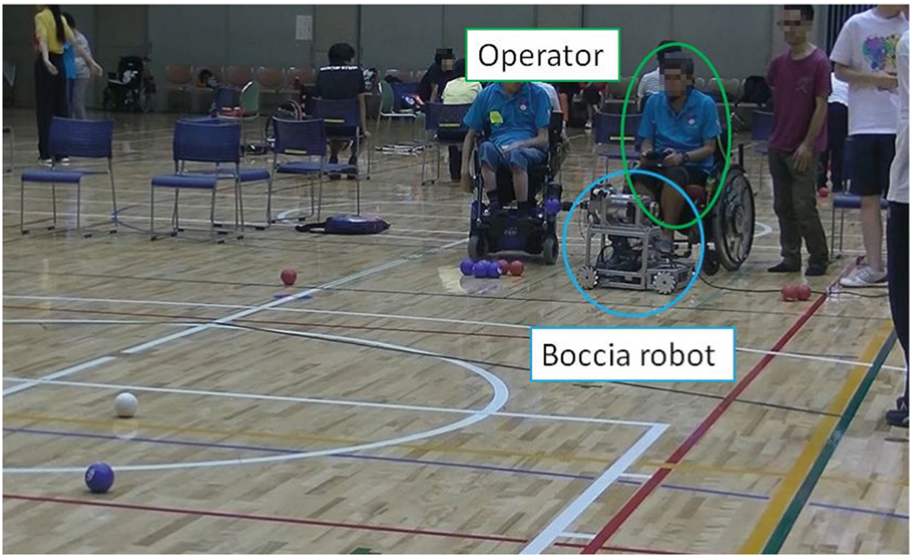

Fig. 13. Subjective evaluation experiments

of people answered "It's difficult to operate." One of the reasons that people answered "It's difficult to operate" is thought to hesitate to adjust the throwing parameters α and β. Although the throwing distance estimated by α and β was presented, the person who operates the robot for the first time did not know how the throwing distance changes by α and β. Based on the field experiments, it was found that an interface that made it easier for the beginners to operate the robot had to be developed.

6 Conclusions

In this study, we developed the boccia robot as a robotic throwing device to introduce in boccia games. In addition, we developed the throwing support system that presents the estimated throwing distance based on the combination of throwing parameters. By this throwing support system, the operator can intuitively imagine the ball thrown and adjust the throwing parameters. Then, it was confirmed by the field experiments that the boccia robot had sufficient performance to play boccia games, and that many people could enjoy it. However, it was found that there was still a problem in operability.

As future works, to make the boccia robot more widely available for people with disabilities we will implement various operational interfaces besides the gamepad. In addition, we will improve the throwing support system and aim to be a robot that users can operate more easily. And then, we will conduct evaluation experiments with various disabled people. In the evaluation experiments, we will improve usability of boccia robot by feedback of their opinions.

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