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Japanese flower arrangement simulator considering deterioration of flowers

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Abstract: Virtual reality technologies have rapidly improved these days and many systems utilizing the technology have been developed in various fields such as sports, medicine, arts, and so on. Some use cameras to catch the users for self-evaluation during the training, and others employ haptic devices for the trainees to feel the force feedback. Virtual training systems are very useful because the users can train many times repeatedly by using the systems. Then, we have also developed a Japanese flower arrangement simulator called the “Ikebana” simulator, which is a Japanese flower arrangement simulator. The users can learn how to make a flower arrangement with a stereo view and force feedback.

Figure 1 shows the “Ikebana” simulator that we have developed so far. The simulator is composed of a personal computer (PC), two haptic devices, and a stereo display. Figure 1 (a) shows the two haptic devices and the stereo display, while Figure 1 (b) is the image on the display, which shows two cubes that indicate both hands used for the operations, one branch, one flower, and a pin-holder that is called “Kenzan”. Users can grab and move a flower by touching it with the cube model and pushing a button, which is attached to the haptic device. Two haptic devices can be operated independently so that users can grab two different flowers with both hands. They can also manipulate one flower with both hands and bend it as if people operate in the real world.

Here, the most important thing required for training simulators is the consistency between the operations in the virtual space and the phenomena in the real world. The training in the virtual space must have realistic effects as in the real world. We can train the same thing repeatedly with simulators; however, we cannot do the same thing many times in the real world. In the flower arrangement, flowers used in the training cannot be used after some uses due to deterioration. Our previous system did not consider the deterioration of flowers so the users were able to insert the flower into “Kenzan” many times. Therefore, in this paper, first, we summarize the functions of the Japanese flower arrangement simulator we have developed so far and then describe how to consider the deterioration of flowers as the result of the experiment using a real flower.

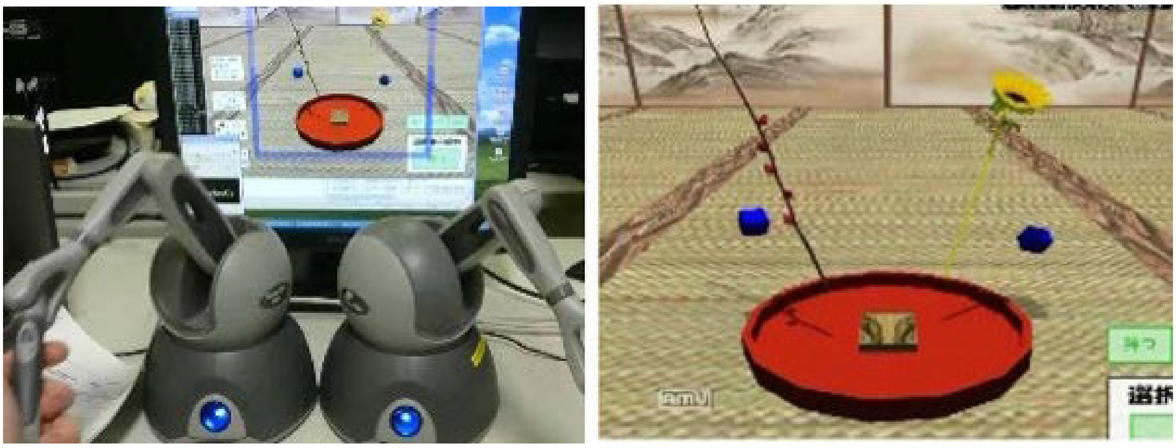

(a) Two haptic devices
(b) Simulator display

Figure 1. Japanese flower arrangement simulator

Keywords: *Flower arrangement, haptic devices, both hand collaboration, repeatability*

1. INTRODUCTION AND RELATED WORKS

With the improvement of virtual reality, various kinds of systems using the technology have been developed. It has been found by the research at San Martin National University that the use of tools using virtual reality technology is significantly related to innovation (Padilla et al. 2022). Then, many systems have been developed so far. One of the most effective fields is sports, and there are several works such as handball (Bideau et al. 2004) and baseball (Mikami et al. 2018). VR systems are also used in medical fields, such as preoperative surgical planning (Nakao et al. 2006) and dental drill training simulation (Ozaki et al. 2011). There is also a training system for calligraphy (Shichinohe et al. 2011), and it is one of the arts and virtual reality systems are also used in many fields of art.

Another field of the arts that is effective for learning by using virtual reality is flower arrangement, which employs live flowers that cannot be used repeatedly. One application is a flower arrangement tool using the leaves of plants made by computer graphics (Kaino et al. 2000). They made images of grass stems, twigs of trees, and leaves using the “Origami” model in a virtual space, and applied them to a flower arrangement. There are also other flower arrangement systems using live flowers. One of them is the collaboration of flower arrangements and music (Yamada 2010). Users insert a flower into a vase put on a wooden table, when music depending on the flower starts. Another system is a fusion between flower arrangement and interactive work (Kodama et al. 2011). When a user selects one flower and puts it into a vase, the color of a wall sculpture that has 16 tile modules changes according to the selected flower. There is also another collaboration system between flower arrangement and interactive projection mapping (Takazaki et al. 2021). The user’s motion is detected by a Kinect sensor, and the flower arrangement made by the user is projected on the mist screen. Flower arrangements now have become very familiar to us and we can enjoy them without real flowers. Then, “Ikebana” competition over the network appeared (Sithu et al. 2014). This competition is held in a networked virtual environment with a haptic device and olfactory sensor. As mentioned above, there is much research related to flower arrangement; however, there is little work on training systems for flower arrangement itself. One of them is a supporting system for flower arrangement (Yokokubo et al. 2012). This system was developed to help beginners enjoy flower arrangements. The users first shoot flowers and add them to the list of the system. Then, the system simulates the arrangement with the list and automatically generates the flower arrangement design. Users can make the flower arrangement just by looking at the screen. This system, however, displays 2D simulation results. Then, they developed an improved 3D system called “TrackKenzan” (Yokokubo et al. 2018; 2019; 2020). Using the pen-typed device representing flowers, users can feel tactile when they insert virtual flowers into a virtual Kenzan. However, users could not operate virtual flowers with both hands.

Therefore, we have been developing a Japanese flower arrangement simulator, with which users can operate flowers in 3D space and can feel the force feedback when they put flowers into a pin-holder called “Kenzan” (Mukai et al. 2009). Flowers are hierarchically modeled, and the model attributes are classified for fast collision detection between flowers and the pin-holder. Moreover, the simulator has been improved by resolving the discontinuity of the response for haptic devices and by adding shadows of objects (Okamoto et al. 2011). Then, bending and cutting methods were implemented (Okamoto et al. 2012). The bending method was still improved by using both hands (Shimada et al. 2018; Yamaguchi et al. 2020). In addition, the reality was improved by considering the resistance forces of flowers against the pins of a pin-holder (Yamaguchi et al. 2021). Here, the most important issue in the systems using virtual reality technology is the consistency of the operations between the virtual space and the real world. The operation using the training simulator must correspond to that in the real world. However, people can insert the same flower into a pin-holder many times repeatedly in the simulator we have developed so far, while the flower cannot be inserted into the pin-holder after several trials in the real world because the stem of the flower is weakened by several insertions. Therefore, we have investigated how many times flowers can be inserted into the pin-holder by measuring the resistance force working between the stem of flowers and the pins of a pin-holder. In this paper, we report the investigation result after the discussion of the development summary of the simulator.

2. FLOWER ARRANGEMENT SIMULATOR

2.1. Architecture

Figure 1 shows the Japanese flower arrangement simulator we have developed so far (Mukai et al. 2009; Okamoto et al. 2011; 2012; Simada et al. 2018; Yamaguchi 2020; 2021), and Figure 2 is the simulator display, which shows the flower materials used in the training and the result of the training with the sample. After users have finished the training, they can see the result in any direction and evaluate the training results by comparing them with the sample.

Figure 3 shows the software architecture of the simulator. When a user operates the haptic devices, 6 DoF (Degrees of Freedom) data, which include 3 positions and 3 rotations, are obtained by the PC. The position coordinates of the vertices constructing the flower objects are transformed into the world coordinate system, and the collision detection calculation is performed between objects such as flowers and a pin-holder. The reactive force is calculated with the result of the collision detection and conveyed to the user through the haptic devices, which response speed must be 1,000 [Hz]. On the other hand, two images are generated by computer graphics, and the user can get a stereo view on the screen with a pair of polarized glasses, which response speed must be 30 [Hz].

「ヒマワリ」をすべて挿し終わったら 次へ をクリックしてください。

Figure 2. Guideline of the simulator

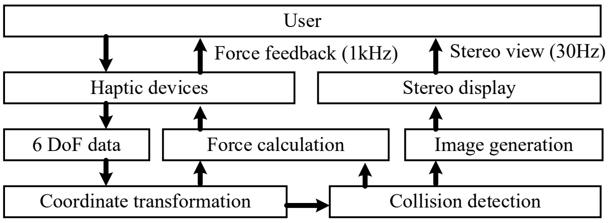


Figure 3. Software architecture

2.2. Flower modelling

A flower is composed of three elements: petal, stem, and leaf, and each part is also constructed with plural parts. For fast collision detection, the models have three kinds of attributes: Active, Inactive, and Passive. Only objects having "Active" or "Passive" attribute are the target of collision detection, and the object with "Inactive" is ignored for collision detection (Mukai et al. 2009).

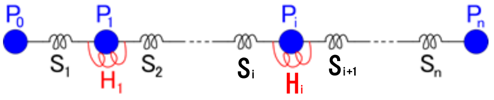
The stem of the flower is modelled with multiple parts to be bent for the arrangement, and each part is connected with a spring model. Figure 4 shows the spring model used in the simulator. In the figure, P_i $(i = 0,1,\dots,n)$ is the mass point, S_i $(i = 1,\dots,n)$ is the structure spring, and H_i $(i = 1,\dots,n-1)$ is the hinge spring. The force $\mathbf{F}_i$ working at the mass point P_i is calculated with Eq. (1) according to Hooke's law (Okamoto et al. 2012). There is also a hinge spring at each mass point so that the restoration force $\mathbf{F}^{\mathrm{t}}_{\mathrm{i}-1}$ or $\mathbf{F}^{\mathrm{t}}_{\mathrm{i}+1}$ works by rotation. Then, the coupling force $\hat{\mathbf{F}}^{\mathrm{t}}_{\mathrm{i}-1}$ or $\hat{\mathbf{F}}^{\mathrm{t}}_{\mathrm{i}+1}$ should be added to prevent translation. The forces are calculated with Eqs. (2) and (3).

$$\mathbf{F}_i = \begin{cases} k\Delta d_1 \boldsymbol{e}_1 & (i=0) \\ -k\Delta d_i \boldsymbol{e}_i + k\Delta d_{i+1}\boldsymbol{e}_{i+1} & (0<i<n) \\ -k\Delta d_n \boldsymbol{e}_n & (i=n) \end{cases}, \ldots\ldots.(1)$$

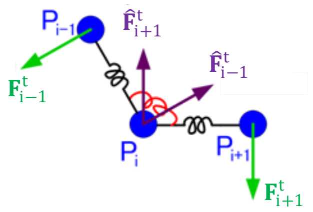
$$\mathbf{F}^{\mathrm{t}}_{\mathrm{i}-1} = \{k\Delta\theta_i \boldsymbol{n}_i \times (-\boldsymbol{e}_i)\}/l_i = -\hat{\mathbf{F}}^{\mathrm{t}}_{\mathrm{i}-1}, \ldots\ldots\ldots\ldots\ldots (2)$$

$$\mathbf{F}^{\mathrm{t}}_{\mathrm{i}+1} = (-k\Delta\theta_i \boldsymbol{n}_i \times \boldsymbol{e}_{i+1})/l_{i+1} = -\hat{\mathbf{F}}^{\mathrm{t}}_{\mathrm{i}+1}, \ldots\ldots\ldots\ldots (3)$$

where k is the spring constant, Δd_i is the displacement from the initial point P_i, $\boldsymbol{e}_i$ is the unit vector from P_{i-1} to P_i, $\Delta\theta_i$ is the angular displacement from the initial angle of H_i, $\boldsymbol{n}_i$ is the normal vector of the plane composed of P_{i-1}, P_i, and P_{i+1}, and l_i is the length of the structure spring S_i.



(a) Spring model



(b) Torques generated by bending

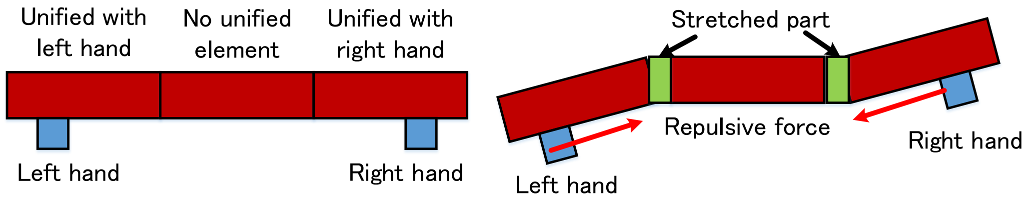
Figure 4. Spring model and generated torques

2.3. Repulsive force and response speed

In the virtual space, the repulsive force is calculated according to the depth, by which the object is inserted into another one. However, the object cannot be inserted into another one if they are rigid bodies. Then, the position difference between the display and the physical is required for the repulsive force calculation. There is also another difference in the response speeds between the haptic device and the stereo display. The response speed of the haptic device is 1,000 [Hz], while that of the stereo view is 30 [Hz]. Then, the flower position is checked with 16 [Hz], which is about half of the stereo view response time. The position of the flower is estimated according to the moving vector with 100 [Hz], and the same force is used 10 times because the response speed of force feedback is 1,000 [Hz] (Okamoto et al. 2011).

2.4. Both hand operation

In the simulator, users can move the flower by touching it with the cube model representing a hand, when the cube model and the flower are unified. There are two haptic devices and they are operated independently. Then, two cubes cannot be unified. Therefore, each cube model is unified with a different element that constructs the flower, and each element moves independently according to each hand motion. In this case, there is an element that is not unified with either hand. If each hand moves differently, the length of the element changes. Then, the repulsive force is calculated according to the length change, and the force is conveyed to each haptic device to keep the length. Figure 5 (a) shows the state where each hand is unified with a different element of the flower, and there is also another element that is not unified with either hand. If each hand moves independently, the element that is not unified with either hand should be stretched or shrunken to keep the length of the flower. The green regions are the stretched parts in Figure 5 (b). Then, the repulsive force works at each hand, which direction of the force is reversed to each other.



(a) Flower unified with both hands (b) Repulsive force to keep the length

Figure 5. Model unification and both-hand operation

Users can bend the flower with two haptic devices as shown in Figure 6. If the tips of the two devices are attached and the bending angle θ is generated, the displacement at each element point of the model can be calculated. As shown in Figure 7, two index fingers are the supporting points, and the flower is pushed at point C by two thumbs, where two supporting points are indicated as A and B, and the length between A and B is set as L. Figure 8 shows the displacement by the bending. The displacement $\delta p(x_i)$ at x_i by the bending and the force $\boldsymbol{F}^b$ at the power point C are calculated as follows where E is the Young's modulus and I is the geometrical moment of inertia (Shimada et al. 2018; Yamaguchi et al. 2020).

$$\delta p(x_i) = \begin{cases} \frac{\mathrm{L}}{2\tan(\theta/2)}\left\{3\frac{x_i}{\mathrm{L}} - 4\left(\frac{x_i}{\mathrm{L}}\right)^3\right\} & \left(0 \le x_i \le \frac{L}{2}\right) \\ \frac{\mathrm{L}}{2\tan(\theta/2)}\left\{3\frac{\mathrm{L}-x_i}{\mathrm{L}} - 4\left(\frac{\mathrm{L}-x_i}{\mathrm{L}}\right)^3\right\} & \left(\frac{L}{2} < x_i \le L\right) \end{cases} \quad ..(4) \qquad \boldsymbol{F}^b = \frac{24EI}{\mathrm{L}^2\tan(\theta/2)}(0 < \theta < \pi) \quad ..(5)$$

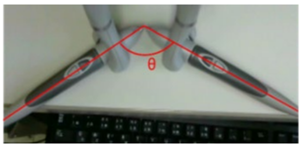


Figure 6. Both-hand bending

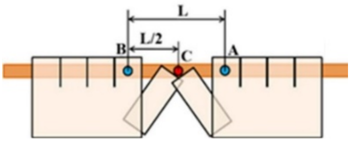


Figure 7. Power and supporting points

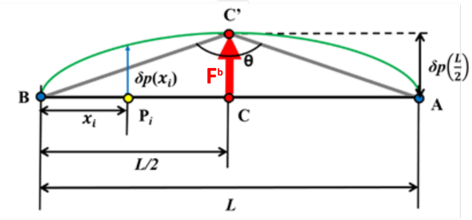


Figure 8. Displacement by bending

2.5. Resistance force of a hard branch

Figure 9 shows the components of the stem of a hard branch, which are epiderm, cortex, and pith. The epiderm is the most outside surface and is very thin. Then, we assume that the stem is composed of just two elements: cortex and pith. Table 1 shows the resistance force of each element, which was measured with a sclerometer and a nail that has the same shape as the pin of the pin-holder.

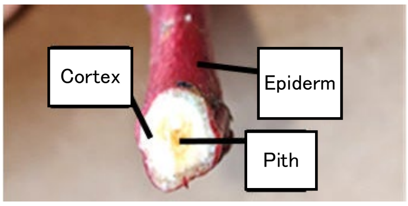


Figure 9. Components of the stem

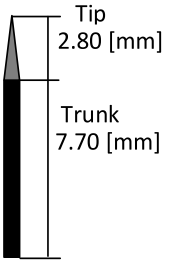
Table 1. Resistance force [gf/mm]

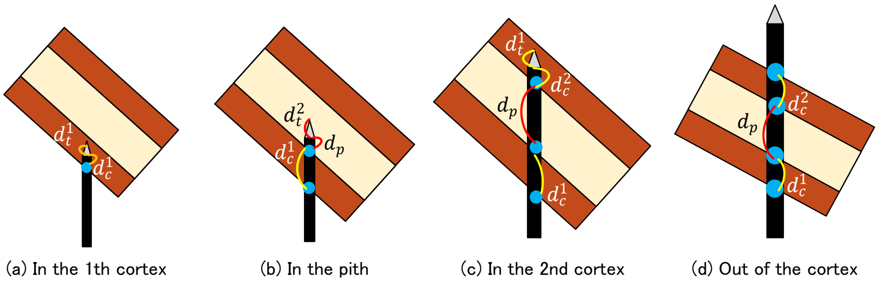
Target area	Cortex	Pith
Tip	711	40
Trunk	316	7

Figure 10 shows the shape of the nail used in the measurement, which has cone and cylindrical shapes at the tip and the trunk, respectively. Then, the resistance force changes depending on the insertion position of the nail. However, we assume that the resistance force is constant for both the tip and trunk, and it depends only on the length, with which the pin touches the cortex or the pith, although the force values are different according to Table 1.

Figure 11 shows four different types of insertion of the pin into the stem of the flower. In the figure, d_t^1 and d_t^2 are the lengths of the tips in the cortex or the pith, respectively. d_p is the length of the trunk in the pith. d_c^1 and d_c^2 are the lengths of the trunks in the first and the second cortexes, respectively. The resistance force $\boldsymbol{F}^h$ is calculated with Eq. (6) (Yamaguchi et al. 2021).

$$\boldsymbol{F}^h[gf/mm] = 7d_p + 316(d_c^1 + d_c^2) + 711d_t^1 + 40d_t^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$





(a) In the 1th cortex (b) In the pith (c) In the 2nd cortex (d) Out of the cortex

Figure 10. Nail shape **Figure 11.** Four different types of insertion depending on the tip position

3. DETERIORATION OF FLOWERS

3.1. Resistance force of a soft branch

In the real flower arrangement, there is a limitation for the insertion count of one flower. The bottom of the flower is broken after several insertions, and the flower cannot be inserted into the pin-holder or the flower falls because of a lack of enough resistance, especially for a soft branch. Then, we have investigated how many times a sunflower that is a soft branch can be inserted into a pin-holder until the bottom is broken or the flower falls after it is inserted in the pin-holder. In the experiment, a sunflower, which length is 230 [mm], was inserted into a pin-holder with an insertion angle of 45 [degrees] against the horizontal line. The insertion was repeated 15 times, and the average insertions were counted. The average insertions until the bottom was broken was 2.6, while the average insertions until the flower fell was 5.8

Table 2 is the experimental result measured by a sceremeter, which shows that the maximum force lowers as the number of insertions increases; however, there is little difference after 3 insertions and the difference can be considered an experimental error. Then, the average from 3 to 6 is shown at the bottom of the table. In addition, the diameter of the flower is about 7.5 [mm], and the interval of pins on the pin-holder is about 4.0 [mm], so 4 pins are inserted into the stem of the flower. Then, the maximum forces for 4 pins are shown in the middle of the table. The sum of the resistance forces $\boldsymbol{F}^s$ is calculated as follows.

$$\boldsymbol{F}^s = \sum_{i=1}^{n} \boldsymbol{f}_i^s < m\boldsymbol{g}r\cos\theta \tag{7}$$

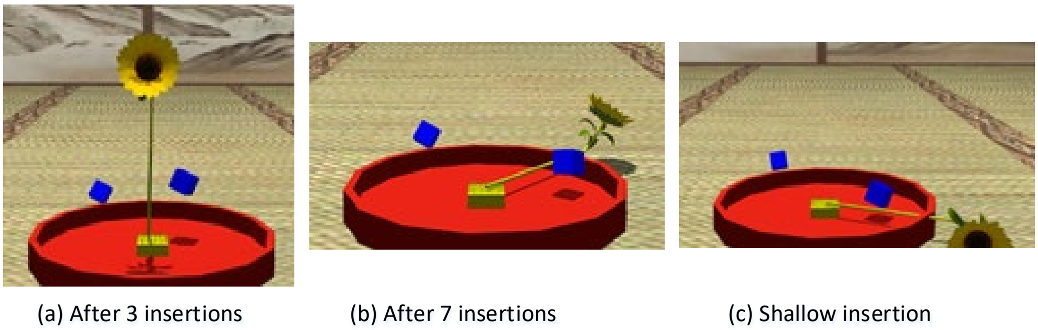
Where F_i is the force of 1 pin, n is the number of inserted pins, which is 4 in the case, m is the mass of the flower, $\boldsymbol{g}$ is the gravitational acceleration, r is the distance between the bottom of the pin and the center of the gravity, and θ is the angle between the flower direction and the horizontal line, which was 45 degrees in the experiment. For the calculation, the maximum force for 4 pins is used as $\boldsymbol{F}^s$ for 1 and 2 insertions, and the average is used after 3 insertions because there is little difference among 3-6 insertions.

Table 2. Resistance force of sunflower

Number of insertions	Max. for 1 pin [gf]	Max. for 4 pins [gf]	Resistance force [gf/mm]
1	121	484	9.3
2	115	460	8.8
3	103	412	7.9
4	101	404	7.7
5	98	392	7.5
6	97	388	7.4
Average of 3-6	100	399	7.6

3.2. Simulation results

Figure 12 shows the results. Figure 12 (a) is the result after 3 insertions, where the resistance force of the pins was enough so that the flower stands. Figure 12 (b) is the result after 7 insertions when the resistance force was not enough and the flower fell. On the other hand, Figure 12 (c) is the result after only 2 insertions; however, the depth of the insertion into the pins was not enough, so the sum of the resistance force was not enough and the flower fell as a result.



(a) After 3 insertions (b) After 7 insertions (c) Shallow insertion

Figure 12. Flower insertion results depending on the number of insertions and the depth

4. SUMMARY AND FUTURE WORKS

This paper describes the method of the flower arrangement simulator we have developed so far, and investigates how many times one flower can be used to make consistency between the operation in the virtual space and the phenomenon in the real world. In the experiment, it has been found that a flower can stand if the number of insertions is less than the threshold and the resistance force is enough, and it falls when the number of insertions is over the threshold or the insertion depth is not enough.

Now, we can use the Japanese flower arrangement simulator with both hands, the stereo view, and the force feedback. In addition, it has become clear how many times the flower can be inserted repeatedly, and also how deep the flower should be inserted for standing. However, users can see the flower arrangement only in one direction during the training, although the result can be seen in any direction by rotating it after the training has finished. Then, in the future, we have to integrate the mechanism to see and operate the flower in any direction during the training.

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