Tension Based 7-DOF Force Feedback Device: SPIDAR-G

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Abstract

In this paper, we intend to demonstrate a new intuitive force-feedback device for advanced VR applications. Force feedback for the device is tension based and is characterized by 7 degrees of freedom (DOF); 3 DOF for translation, 3 DOF for rotation, and 1 DOF for grasp). The SPIDAR-G (Space Interface Device for Artificial Reality with Grip) will allow users to interact with virtual objects naturally by manipulating two hemispherical grips located in the center of the device frame. We will show how to connect the strings between each vertex of grip and each extremity of the frame in order to achieve force feedback. In addition, methodologies will be discussed for calculating translation, orientation and grasp using the length of 8 strings connected to the motors and encoders on the frame. The SPIDAR-G exhibits smooth force feedback, minimized inertia, no backlash, scalability and safety. Such features are attributed to strategic string arrangement and control that results in stable haptic rendering. The design and control of the SPIDAR-G will be described in detail and the Space Graphic User Interface system based on the proposed SPIDAR-G system will be demonstrated. Experimental results validate the feasibility of the proposed device and reveal its application to virtual reality.

1. Introduction

In general, the physical act of gripping (or grasping) allows human beings to perform several important functions including using instruments to hit, translate, rotate, puncture and cut objects. Before doing the above-mentioned tasks, we select the necessary instruments by grasping it. Depending on the size and shape of the object, we can generally grasp an object using our thumb and our other fingers. So far force-feedback devices have presented users with simple ways of representing this grasping function, such as pushing a button on a mouse or keyboard. We believe that an effective force-feedback device should not be limited to feedback on only the differential sense of width. Force-feedback should also be coupled with grasping. The purpose of this paper is to realize such a tension-based 7 DOF force-feedback device that can allow users to not only grasp an object, but to also sense the width of an object as in real life object manipulation.

2. Structure of SPIDAR-G

We suggest a new mechanism for the grip. The new grip allows its users to manipulate with 7 DOF by grasping the grip between the thumb and other fingers. The proposed mechanism is broken into 2 hemispherical structures. If the user grasps the grip using thumb and fingers, the 2 rods rotate depending on the magnitude of the grasp force. Hence, it is possible to control the grasp functionality of the grip. The basic structure of the cross type grip is shown in figure 1. The crossing degree changes with the magnitude of the grasping force and is used to quantify the action of grasping.

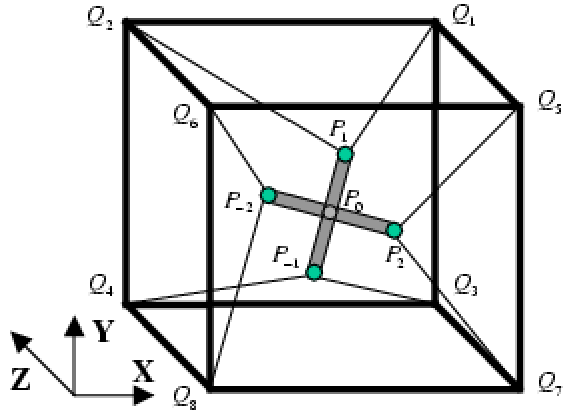


Figure 1. Basic structure of SPIDAR-G

3. Calculation of position and tension

To calculate translation, rotation, and grasp, we have to solve each extremity of grip from the length of 8 strings.

$$l_i = \|Q_i - P_{(i)}\| \qquad (i = 1, \cdots, 8)$$

To display force vector to cross type grip, we have to solve the tension vector. However, the tension vector must be a positive value vector $(\tau_i \ge 0, i = 1, \cdots, 8)$. If we solve the quadratic programming problem, we can obtain the tension vector.

$$\|q - A\tau\|^2 \rightarrow \min$$

$$s.t.\ \ \tau_{\max} > \tau \geq 0$$

Because SPIDAR-G uses the tension of strings to display force, there are certain location within the frame where SPIDAR-G can not display appropriate forces. However, near the center of frame, SPIDAR-G can display 7 DOF force appropriately.

4. Manufactured SPIDAR-G system

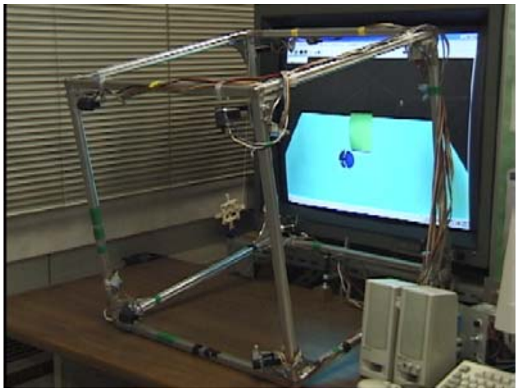


Figure 2. Manufactured SPIDAR-G

We positioned the grip of the SPIDAR-G on markers located every 5cm on the X-axis and Z-axis (without applying rotation) and determined the average grip position with the method defined in section 4. A start point of (0,0,0) was taken in the center of frame. The results are shown in table 1.

Table. 1 Average grip positions and the differences with respect to the marker (Unit in cm.)

	-20	-15	-10	-5	0	5	10	15	20
X	-19.7	-14.7	-9.9	-4.9	0	4.9	9.9	14.7	19.6
Z	-20.4	-15.4	-9.7	-4.9	0	4.8	9.6	14.7	20.4

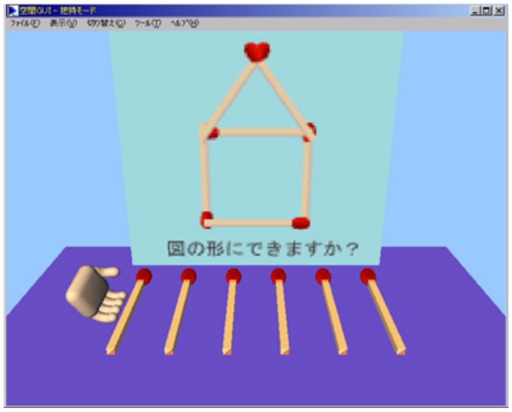
The input error of the SPIDAR-G proved to be below ±4 mm when measured within a 40-centimeter cube region positioned in the center of the frame. In addition, a 45 degree rotation of the grip was applied about the Y-axis and the grip was translated along the X and Z axis. While maintaining a 45 degree rotation, the angle was determined. The results are shown in table 2. The error resulting for measuring grip orientation is most likely due to inaccurate string measurement. The rotation errors are larger in magnitude than the translation errors, indicating greater sensitivity to inaccuracies in string length measurement. If the angle of a cross typed grip is between 20degree and 50 degree, we assumed that the grip is in grasp status. Otherwise, release is assumed. Given these criteria, every point within a 40-centimeter cubical region positioned in the center of the frame could be grasped and released.

Table. 2 Average rotation angle and the differences with respect to 45 degree about Y-axis (Unit in degree)

Distance (cm)	-20	-15	-10	-5	0	5	10	15	20
Angle (X-axis)	41	42	42	43	43	42	42	41	40
Angle (Z-axis)	40	40	41	43	43	43	41	40	40

5. SGUI system

We created a 3D grip device for the space Graphic User Interface (SGUI) to be used with the SPIDAR-G. This application is shown in figure 3.



図の形にできますか？

Fig 3. Link matches together

6. Conclusion

We described a tension based force feedback device with 7 DOFs. We have shown a new way to calculate position with 7 DOFs and to display force over 7 DOFs using a grip. Through examples, we have demonstrated the effectiveness of our proposed SPIDAR-G when performing 3D tasks. The example proves that our contrived SPIDAR-G provides users with not only effective translation and rotational manipulation, but also grasp, which is accurate and efficient. Future work will be devoted to developing more robust algorithms that more accurately measure string length

7. References

[1] Makoto Sato, Seahak Kim, Yasuharu Koike, "A Proposal of 7 DOF Force Display using 8 Strings" Correspondences on Human Interface, PP85-90, 12-13, June, 2000

[2] Seahak Kim, Masahiro Ishii,Yasuharu Koike,Makoto Sato,"Development of SPIDAR-G and Possibility of its Application to Virutal Reality", VRST2000, 22-25, Oct, 2000