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Active Link Mechanism for Physical Man-machine Interaction

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Abstract:

In this paper, newly developed interface devices, which realize Physical Man-machine Interaction (PMI) between machines and persons, are reported. Developed interface devices are an active tetrahedron and an active icosahedron realizing PMI. Nine-DOF micro spherical joints and pressure control pneumatic cylinders were developed to realize the active tetrahedron, while fifteen-DOF micro spherical joints are developed for active icosahedron.

The tetrahedron successfully realizes "virtual touch"; the operators feel actions, forces, and shapes of the virtual objects in PC and also move and deform them. Real time PMI is realized by using MSC.VisualNastran 4D. MSC.VisualNastran 4D is a mechanism analysis software, which can make motion analysis in real time. The active icosahedron realized to present shape of virtual object in PC simulated by MSC.visualNastra 4D, showing the potential of the devices as haptic interface.

1. Introduction

Recently many researchers have been developed various types of haptic interfaces. Those interfaces are classified into six groups as follows, arm type, parallel link type, mouse type, wearable type and other type. PHANToM is a typical model classified into arm type. As parallel link type, there are a force-displaying device using pneumatic parallel manipulator [1] and a compact six DOF haptic interface [2] and so on. As mouse type, there are 2 DOF flat actuator for tactile display [3], active mouse [4] and so on. As wearable type, there are CyberGrasp, spider-8 [5].

Focusing on the device appearance, haptic interfaces are divided into concentrated model and distributed model. Arm type, parallel link type and mouse type are classified into category of concentrated model, which show physical information at one point. Wearable type is classified into distributed model, which shows distributed physical information. The number of distribution type is relatively small than that of the other.

We have developed an active polyhedron link mechanism realizing physical man-machine interaction. Active link mechanism belongs as to distribution type. Haptic polyhedron mechanism is a fundamental element to form the plane, sphere and complex shape in order to present force, motion, touch, deforming and so on.

To present finer deformation and forces each links need to be downsized and integrated. Recently various functional micro devices are developed and commercialized. Examples of there are micro sensors, motors, gears, bearings and connectors. They are small enough to be built into small haptic devices, making possible to realize highly integrated and high performance haptic devices.

As shown in Fig.1, physical man-machine interaction (PMI) is based on bilateral physical information exchanges between man and machine. Normally man-machine interfaces except haptic

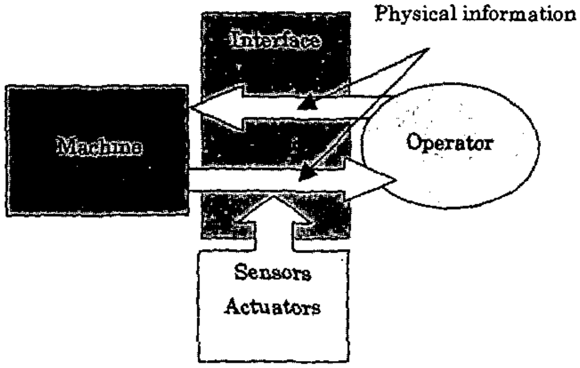

Fig. 1 Physical man-machine interaction

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interface deal with only one-way information from man to machine. As mentioned above, various element devices have been downsized by MEMS technology and enable to be built into small haptic devices. Those devices permit physical man-machine interaction with information of shape, motion, force, stiffness and inertia bi-directionally. Operators can feel "virtual touch" of virtual objects in PC and give them several influences through these interfaces. We believe one possible application of those devices is in modeling process in CAD operations and in art. Operator could create virtual model with his hand through haptic interface in PC as if he/she directly touched it.

2. Active tetrahedron

The first prototype model of active tetrahedron is shown in Fig. 2. Active tetrahedron consists of six pneumatic cylinders, six liner encoders, six pressure sensors, four spherical joints with nine degree of freedom and pneumatic connectors. The length of cylinder is 180 mm in normal and the moving stroke is 40 mm. Cylinder motion is detected with liner encoder mounted on cylinders. The cross sectional area of a pneumatic cylinder is 28.3 mm^2. The diameter of a pneumatic tube is 2 mm and it makes the size of link mechanism reduced.

The spherical joint with nine-degree of freedom is at the apex of tetrahedron as shown in Fig. 3. The spherical joints consist of three teflon balls and aluminum plates. Teflon balls are mounted on each end of pneumatic cylinder and piston, enabling free-orientation of the cylinders in every direction.

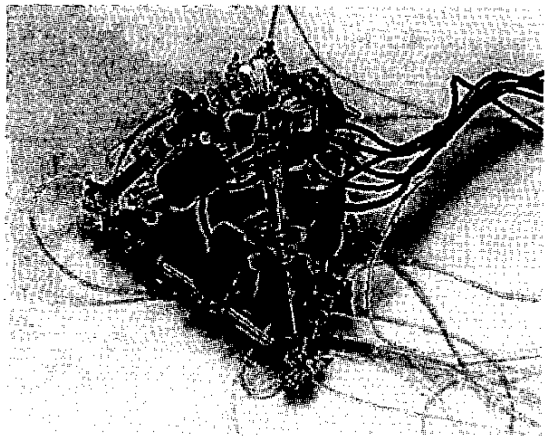

Fig2. Active link mechanism

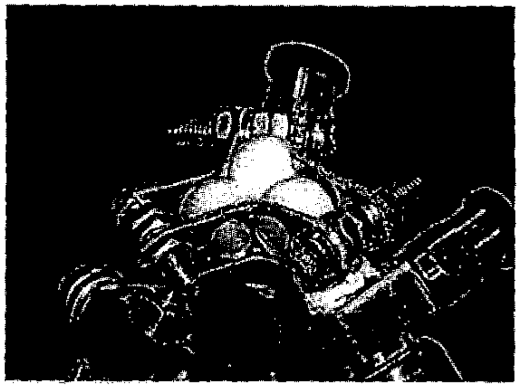

Fig. 3 Nine DOF spherical joint

Generally speaking, degree of freedom of mechanism is shown as follows:

$$f = 6(n-1) - \sum_{n=1}^{6} (6-n) p_n \qquad (1)$$

where f is degree of freedom, n is the number of machine element, p_n is the number of pairing elements that have n degree of freedom.

Supposing that the joint is small enough to neglect its orientation and cylinders and pistons don't rotate at each other, equation (1) results in f=12, where n=12, p_3=8, and p_1=6. Six of these twelve DOF are from motion of expansion and construction of cylinder; remaining six is rotation of universal joints. Therefore, cylinder length control uniquely leads shape of the active tetrahedron.

Actually, the apexes aren't very small, and cause small mechanical play.

3. Control system

As shown in Fig. 4 the key components of this system are an active tetrahedron, V/P controllers, driver software and a linkage mechanism simulator, Visual Nastran4D. Shape of the active tetrahedron deformed by an operator is detected with liner encoders, and sent to driver through a counter board, while axial force acting on the cylinder is acquired with pressure sensors, and sent to driver. The driver receives physical information from the active links and exchanges data with VisualNastran4D. VisualNastran4D has the same mathematical model as the active tetrahedron; it has characteristic parameters such as force, stiffness, shape, and motion, which users can set arbitrarily. When user deforms the real active tetrahedron, virtual model in PC also changes its shape and the driver receives the results from VisualNastran4D promptly. Based on them the driver controls force and length of the pneumatic cylinder through V/P controller. Operator can feel "virtual touch" in real time, with visual information of the model on display.

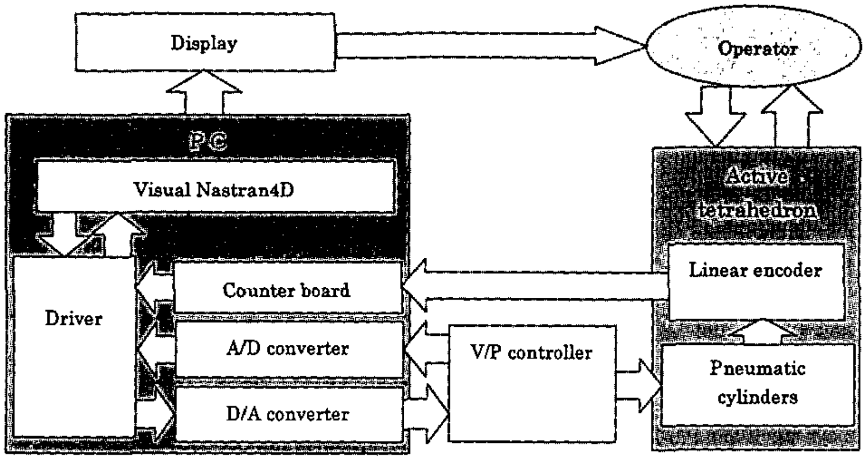

Fig. 4 Block diagram of active link mechanism system

4. Experiment with active tetrahedron

We conducted the experimental tests to confirm that the active tetrahedron system works successfully to realize physical man-machine interaction. When an operator deforms the active tetrahedron, VisualNastran 4D calculates kinematics and dynamics to transform the active

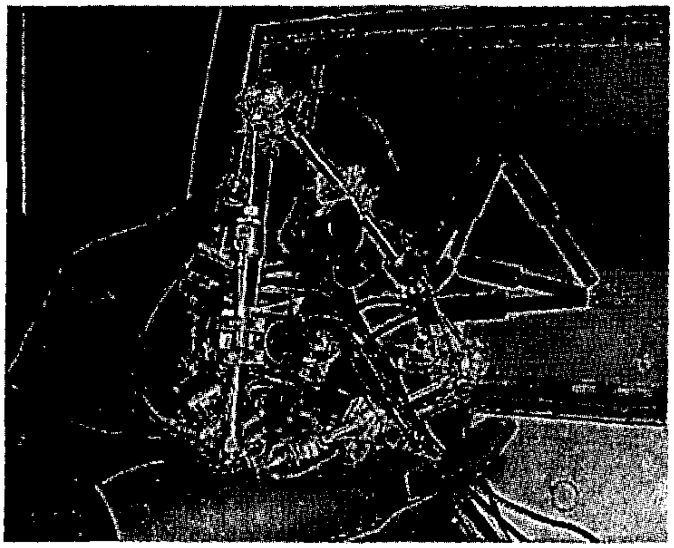

Fig. 5 PMI via the active link mechanism

links and the virtual model in PC. Based on obtained results the driver makes the operator feel its stiffness, force, motion and shape.

5. Geometrical analysis of polyhedron

As the second prototype we were planning to expand the DOF of active link mechanism. To develop the 2nd prototype, which is higher order polyhedron, geometrical analysis was made using a simple prototype linkage model shown in Fig. 6. As shown in Fig. 6, icosahedron model can be modified to various shapes. At the lower left the model is very flat. On the other hand the model at the upper right is formed like a rugby ball. Extension ratio, which is maximum length / minimum length of links, should be high to realize variety of shape. The ratio of the model is 1.64.

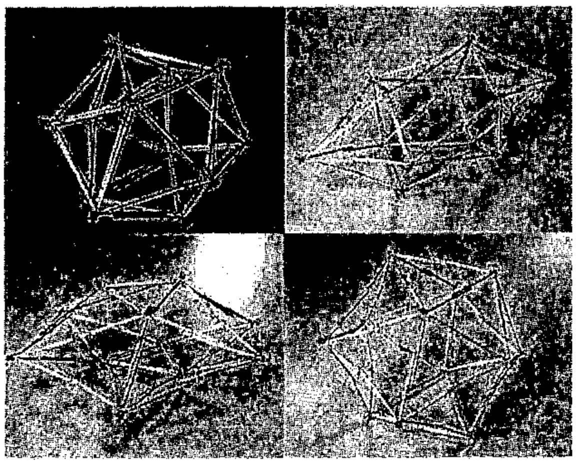

Fig.6 The conceptual model of icosahedron

To design polyhedron linkage mechanism consisting of links and joints it is important to consider its linkage geometries and its degree of freedom carefully, otherwise the shape of the mechanism is not determined uniquely.

We calculate the DOF of active icosahedron using equation (1): n is sixty, p_3 is twenty-four and p_1 is thirty. Thus f=354-(144+150) is sixty. Thirty out of sixty DOF are with expansion and contraction motions of the pistons and the others are with rotation of cylinder, which have no effects on the shape of the icosahderon. Thus, the shape of the mechanism is determined uniquely.

6. Active icosahedron

We developed an active icosahedron as shown in Fig. 7. The mechanism consists of 30 pneumatic cylinders. The apexes of the icosahedron are twelve.

Five cylinders gather at an apex. So new spherical joint was developed as shown in Fig. 8. This joint has fifteen DOF in total. The ball on both ends of the cylinder is teflon ball, which is 6.35 mm in diameter. A joint diameter is 22 mm. The range of orientation is big enough to deform the active tetrahedron. This model is still at the developing stage and it has no sensor now.

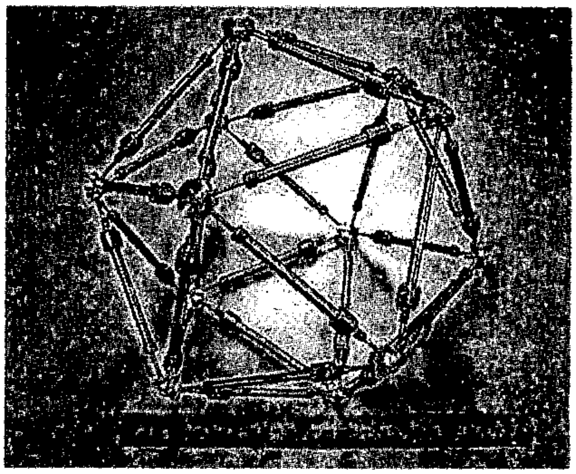

Fig.7 Active icosahedron

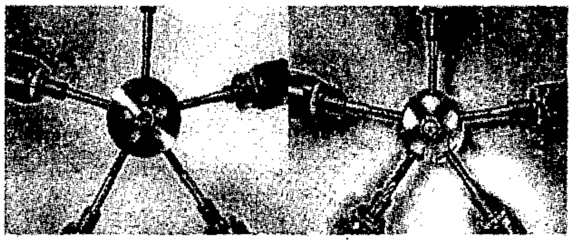

Fig.8 Spherical joint with fifteen degrees of freedom

7. *Modification of active tetrahedron*

We made experiment to know how the active tetrahedron can change its shape with applied pressure as shown in Fig 9. The control system is shown in Fig. 10.

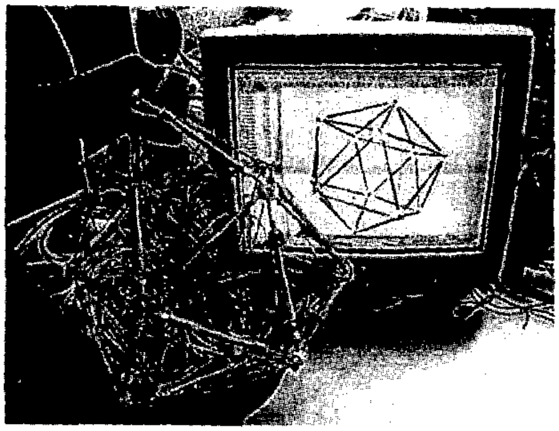

Fig. 9 Presentation shape with active icosahedron

It was found that the active icosahedron worked in conjunction with virtual model on the display, the motion of which is calculated by VisualNastran4D.

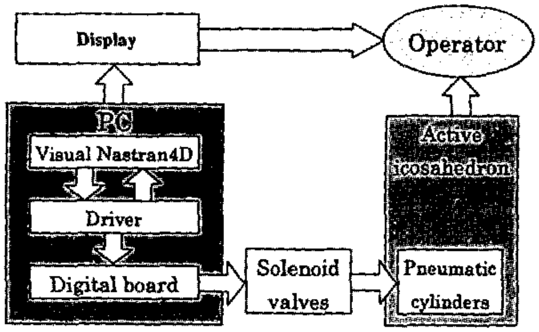

Fig. 10 Block diagram of active icosahedoron experimental system

The current system controls pneumatic cylinders with the open loop without sensors. So it doesn't work as haptic interface at present but it can display various shapes.

Deformed icosahedron with pressure is shown in Fig. 11. Left figure corresponds to the lower left case of Fig.6 and right figure corresponds with the upper right case of Fig.6. Difference of the shape deformation between Fig.6 and 11 results from the expansion ration; the ration of the model in Fig. 6 is 1.64 while that of the model in Fig. 7 is 1.28.

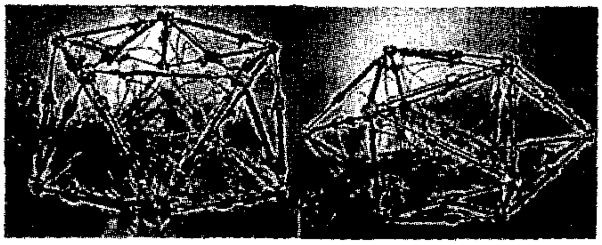

Fig. 11 Deformed active icsahedron

8. Conclusion

We have developed active link mechanisms for physical man-machine interaction. The active tetrahedron and active icosahedron realized to present physical information.

The active tetrahedron successfully makes "virtual touch"; the operator feels actions, forces, and shapes of the virtual objects and also moves and deforms them.

The active icosahedron shows various shape and motion of the virtual object.

Acknowledgements

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