Design of a Novel 3-DOF Spherical Actuator Using VCM

H.Y. Kim[1], D. G. Gweon[1]
[1]*Mechanical Engineering Departments, KAIST, Korea*
gydud0717@kaist.ac.kr

Abstract

We propose a novel 3-DOF (degree of freedom) spherical actuator which is easy to control. The original idea is to use VCM principle. The novel spherical actuator has four pair spherical yokes, one ring type magnet, one spherical shape back yoke, and can be rotated in three axes. The greatest advantage of this novel actuator is that it is convenient to control. Three rotational axes which are actuated by Lorentz forces are decoupled, therefore the actuator is easy to control in three rotational directions by independent torque. The concept designed actuator was simulated by 3D FEM analysis program, and we verified a realizable possibility of proposed novel 3-DOF spherical actuator.

1 Introduction

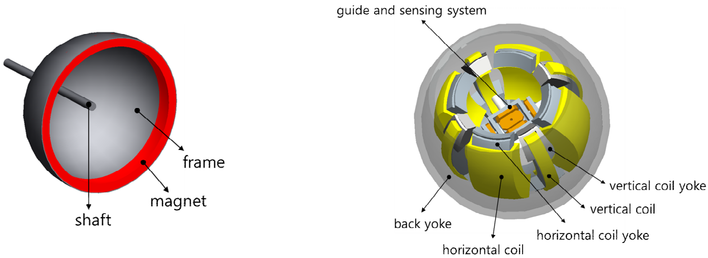
A spherical acutator or a spherical motor can be used in robotics, manufacturing and assembly systems. Spherical auctuators with multiple degrees of freedom have been the subject of research for several decades [1]. At present, two or three separated 1-DOF rotational motors were used for multi-degree-of-freedom rotational motion. However, this kind of actuating system which has several numbers of simple motors have to use additional complex gears and heavy transmission system. This inevitably compromises the dynamic performance and servo-tracking accuracy, due to the combined effects of inertia, backlacsh, nonlinear friction, and elastic deformation of gears [2]. A 3-DOF spherical actuator can be overcome above combined effects which can adversely affect the system performance. Despite these advantages, generally developed previouse spherical actuators have to need very complicated torque modeling and control algorithm [3]. We propose a novel 3-DOF (degree of freedom) spherical actuator which is easy to control. The original idea is to use VCM principle. Three rotational axes which are actuated by Lorentz forces are decoupled, therefore the actuator is easy to control in three rotational directions by independent torque. In this paper, we designed 3-DOF rotational actuator which consists of magnet, yoke and coil.

2 Concept of the Proposed 3-DOF Spherical Actuator

In this section, the concept of the proposed 3-DOF spherical actuator is described. Fig. 1 shows the conceptual proposed spherical actuator.

2.1 Configuration

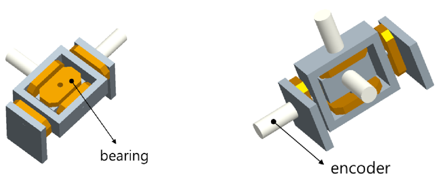
The novel spherical actuator has four pair spherical coil yokes, one ring type magnet, one spherical shape back yoke, and can be rotated in three axes.



(a) Rotor (b) Stator

Fig.1 Concept of the Proposed 3-DOF Spherical Actuator

Fig. 1(a) shows rotor part of the proposed spherical actuator. The rotor consists of ring type magnet, shaft, and frame. The shaft is connected to guide and sensing system for feedback control. Fig. 1(b) shows stator part of the proposed spherical actuator. The stator consists of coil, yoke and sensing guide system. There are two types of the coil and coil yoke. Each type consists of four parts. One back yoke which can raise the flux density of air gap is covering whole stator. A sensing guide system which is connected with shaft of the rotor is in the middle of the total spherical actuator. The guide system used 5 rotary bearings and simple 3-axis gymbal set. (see Fig.2)



(a) Top view (b) Bottom view

Fig. 2 Guide and sensing system

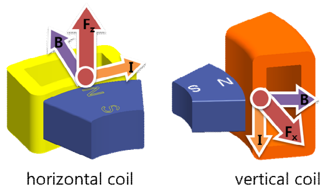


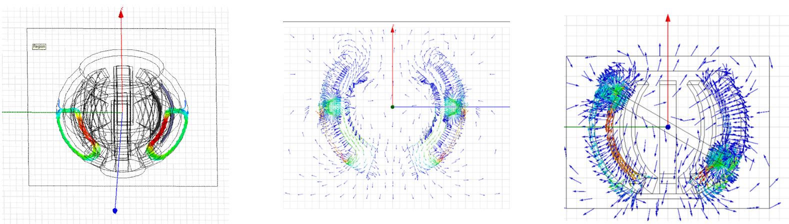
Fig. 3 Lorentz Force

2.2 Principle of the 3-DOF rotational motion.

A proposed 3-DOF spherical actuator is to use Lorentz force which is generated between coil current and magnetic flux. Fig.3 represents the Lorentz force. There are two pair horizontal coils and yokes. One pair horizontal coil produce opposite vertical force each other, this force produce tilt directional torque. Because there are two pair horizontal coils, therefore two tilt directional torques (θ_x, θ_y direction) generated. The working angles of the two tilt direction are ±40°. In a similar fashion, there are four vertical coils and yokes. These vertical coils produce theta directional torque (θ_z direction). The working angle of the theta direction is infinite (±360°). Three rotational direction axes are all decoupled, and each independent torque makes easy to control.

3 Simulation

To verify the proposed 3-DOF spherical actuator, we performed the 3D FEM simulation. The size of the spherical actuator is 200 *mm* and the weight of the rotor is 0.7 kg. All yoke are made of steel, and the magnet part is NdFeB permanent magent. All yoke were so designed as to be not magnetic saturation phenomenon. There are two air-gap between back yoke and coil yoke. First air-gap(2 *mm*) is between back yoke and rotor magnet, and second air-gap(5 *mm*) is between rotor magnet and coil yoke. These air-gaps have a great effect on motor performance. In general, a smaller air-gap has high magnetic flux density and increase the motor torque, however the coil can not be winded sufficiently at small air-gap. Therefore, optimal design process should be necessary to maximize torque performace. However, in this paper, we only verify the feasibility of the novel 3-DOF spherical actuator. After many trials and errors, a simulation are conducted by reasonable values. We will present design optimization framework to determine optimal design variables later.



(a) Flux Line (b) Tilt 0° (c) Tilt 40°

Fig. 4 3D FEM simulation

Fig. 4(a) represents a main magnetic flux line. This flux line enables the flux density to increase at air-gap with coil. And Fig. 4(a) is also represented that the easiest point to magnetic saturation is coil yoke than back yoke. Therefore, we should be careful when we design the coil yoke. Fig. 4(b) and Fig. 4(c) shows that the flux density at air-gap remained at a high level in spite of maximum tilt rotational motion. Table 1 represents simulation results. We confirmed that a novel sherical actuator was a distinct possibility. Also we expect better performance after opimal design process later on.

Table1: Simulation Results

	Turn number of coil	Working angle	Torque
Tilt direction 1 (θ_x)	400	±40°	0.39 Nm /A
Tilt direction 2 (θ_y)	400	±40°	0.41 Nm/A
Theta direction 1 (θ_z)	100	±360°	0.31 Nm/A

4 Conclusion

A new 3-DOF spherical actuator using VCM has been proposed and simulated. The novel spherical actuator. The greatest advantage of this novel actuator is that it is convenient to control. Three rotational axes which are actuated by Lorentz forces are decoupled, therefore the actuator is easy to control in three rotational directions by independent torque. We verified a realizable possibility of proposed novel 3-DOF spherical actuator by 3D FEM simulation. In the near future, we paln to do optimal design process and make actually 3-DOF spherical actuator with gymbal guide and rotary encoder. The proposed spherical actuator can be used for robotic manipulator and reconnaissance camera.

Acknowledement

This research was supported by Agency for Defense Development (ADD) grant funded by the Korea government.

References:

[1] D.Howe, “Analysis, design and control of a novel spherical permanent-magnet actuator,” Electric Power Applications, vol. 145, No. 1, pp. 61-71, Jan. 1998

[2] D.Howe, “Design and control of a novel spherical permanent magnet actuator with three degrees of freedom,” Mechatronics, vol. 8, No. 4, pp.457-468, 2003

[3] Kok-Meng Lee, “Open-loop controller design and dynamic characteristics of a spherical wheel motor,” Industrial Electronics, vol. 57, No.10, pp.3475-3482