Design of a novel 2-DOF Spherical Actuator using VCM

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Abstract

A spherical actuator is capable of multi-DOF (degree of freedom) rotational motion within a single joint. The existing spherical actuator had a problem about modelling, manufacturing, and control. Therefore, most of the developed spherical actuators remain un-commercialized. We propose a novel 2-DOF spherical actuator which is easy to control with a simple structure. The key feature of the proposed spherical actuator is to use the same principle with VCM for easy accessibility of feedback control. The new spherical actuator has 200 mm diameter, a ±35° tilt working range, and a 0.8 Nm/A torque constant.

1 Introduction

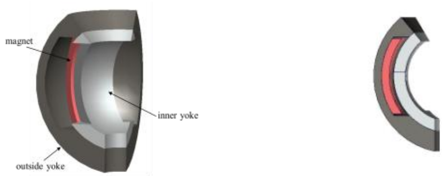
Many industrial applications require multi-DOF rotational motions to achieve various targets. As of yet, multi-DOF spherical motion is realized almost exclusively by using a separate 1-DOF motor for each axis. Each 1-DOF motor is connected by gears and links. While 1-DOF motor can provide accurate motions on a single axis, the combinations of these single-axis motors as multi-DOF devices are rather bulky and inadequate. Because the friction and backlash exist in a motion transmission mechanism, the combined multi-DOF actuator has poor accuracy. For the last few decades, spherical actuators have been a popular research topic around the world because of their advantages of compact size, high motion precision, fast response, direct driven, non-singularity in workspaces and high efficiency [1]. The biggest drawback of the existing developed spherical actuator is that the actuating mechanism is so complicated. It is difficult to design spherical actuators as well as develop their control system due to their nonlinear rotor dynamics, complicated magnetic field analysis, and sensing methods of multi-DOF angles for feedback control [2]. To solve these problems, we designed the novel 2-DOF spherical actuator which is easy to control using VCM principle.

2 Concept of the Proposed 2-DOF Spherical Actuator

The proposed spherical actuator aims to overcome the drawbacks of the existing spherical actuators. Therefore, we plan to solve these problems using a new concept. The new concept is based on the ideas of VCM. There are two types in VCM actuation. One is a moving magnet and the other is moving coil type. Considering a moving mass and heat generation, moving coil type has many advantages compared with moving magnet type. Moving coil type gives the light mass and low heat generation to the spherical actuator. Therefore, we decided to design a stator using magnets and yokes.

2.1 Stator

The stator consists of three parts: outside yoke, inside yoke, and magnet. Fig. 1(a) shows the stator components. The yoke is to improve the performances of the actuator. It is important that the air gap flux density is constant and at a high value. Therefore, the yoke should be designed to satisfy the above two conditions. The stator is divided into four segments for manufacturing. Fig. 1(b) shows cross-section of a quarter of the stator.



(a) a quarter of stator (b) cross-section

Figure 1 Quarter of stator

2.2 Rotor

Fig. 3 shows the proposed rotor. The rotor consists of four coil bobbins. Each coil bobbin is connected with a center ring. The center ring is connected with a guide and a sensing mechanism and has 2-DOF tilt motion.

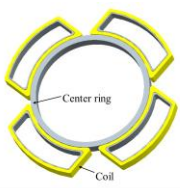
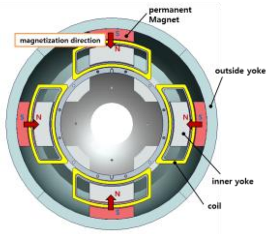


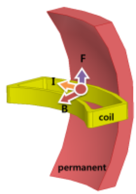
Figure 3 the proposed rotor

2.3 Actuation principle

Fig. 3 shows the proposed rotor. The rotor consists of four coil bobbins. Each coil bobbin is connected with a center ring. Fig. 4 shows the cross section of the rotor with the stator. The principle of the torque generation is presented easily. There are uniform magnetic flux in the between a magnet and an inner yoke. If the currents flow through the coil, the coil generates the force and the actuator becomes rotating. When the rotor is placed the maximum tilt position, the coil bobbin should not contact with any parts of the stator. In other words, the height of bobbin mentioned earlier has enough space.



(a) cross section with stator

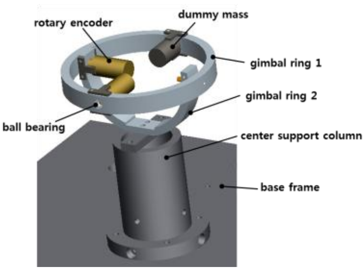


(b) Lorentz force

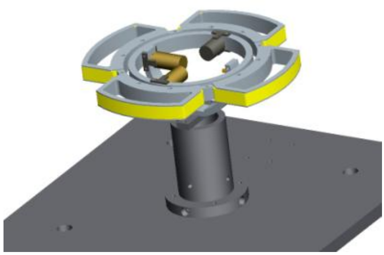
Figure 4 Cross section of the actuator

2.4 Sensing and guide mechanism

The sensing and guide mechanism is placed at the inside of the actuator. Because the inside of the actuator is empty, the sensing and guide mechanism is installed at the inside of the actuator easily. Basically, the proposed sensing and guide mechanism is using a principle of the gimbal system. A gimbal is a pivoted support that allows the rotation of an object about a single axis. The Fig. 5 shows the proposed guide mechanism.



(a) sensing and guide mechanism



(b) sensing and guide mechanism with rotor

Figure 5 Sensing and guide mechanism

3 Simulation results

To verify the proposed spherical actuator, we performed the 3D FEM simulation.
We simulated performances of actuator using optimal values. The temperature of rotor reached 75 ℃, the actuator generates a 0.8 Nm/A torque. The FEM results agree with the analytical results.

Table1: Simulation Results

Description	Analytic model	FEM model	error
Torque	0.79 Nm/A	0.82 Nm/A	3.6 %
Coil Temperature	70 ℃	72~75 ℃	4.1 %

4 Future research

We will perform the optimal design process and we will make the system using final dimension. For feedback control, the 2-rotating axis control algorithm should be developed. The actuator will be tested using developed control algorithm. Finally, the small camera modules will be mounted at the actuator's shaft. We expect that the developed spherical actuator will be widely used in industry.

Acknowledement

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

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