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Design, modeling and first experimentation of a two-degree-of-freedom spherical actuator

Bruno Dehez, Vincent Froidmont, Damien Grenier, Benoît Raucent*

Department of Mechanical Engineering, Center for Research in Mechatronics (CEREM), Université catholique de Louvain,
Institut Stevin, 2, Place du Levant, 1348 Louvain-la-Neuve, Belgium

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Abstract

This paper deals with the design of a two-actuated-degree-of-freedom (DOF) spherical electrical actuator for mobile robotic applications. It presents the different steps involved in this design, namely the choice of the actuation principle (induction), its application to the case of a spherical geometry and two DOFs, the analytical and numerical modeling of the motor, and the sizing and the manufacture of a first one-actuated-DOF spherical prototype. The first experimental results, obtained thanks to our test bench and presenting the torque vs rotor angular speed characteristic of the actuator, are likewise compared with the model predictions.

Keywords: Design; Induction motor; Mobile robots; Modeling; Multi degrees of freedom; Spherical actuator

1. Introduction

Within the field of mobile robotics, one of the objectives is to obtain robot platforms having a perfect mobility [1–4]. Indeed, most existing mobile robots are equipped with conventional wheels. Due to kinematic constraints, these structures cannot, for example, move sideways. This motion restriction can be a problem in various contexts: parking operations, displacements in congested areas such as corridor hospitals, stocking areas, ...

Perfect mobility is achieved when the platform can move instantaneously in any direction of the plane without reorientation of its driving system. In this case, the robot is called an omnidirectional and holonomic robot or, in short, an omnimobile robot.

First studies [4–5] showed the possibility of using off-centered swiveling wheels (“castor wheels”) to achieve such mobility. However, in order to avoid singular positions of the robot, the platform needs to be over-motorized. This complicates the robot control and may therefore lead to trajectory planning errors.

Another solution is based on the “universal wheel” [6], see Fig. 1. On these particular wheels the tread consists of several rollers whose axes are tangent to the wheel circumference, and free to rotate. As the shaft turns, the wheel is driven in a normal fashion in a direction perpendicular to the axis of the driven shaft. At the same time, the roller can rotate allowing a free motion perpendicular to the roller axis. An omnimobile platform can be designed by combining three or more such universal wheels.

The principal drawbacks of such a structure [7] are that the load capacity and the surmountable bump height (e.g. electrical cables, doorsills, ...) are limited by the diameter of the roller and not, as in classical solutions, by the diameter of the wheel. Furthermore, this structure is sensitive to vibrations due to the

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*Corresponding author. Tel.: +32-10-47-25-08; fax: +32-10-47-25-00.

E-mail addresses: dehez@prm.ucl.ac.be (B. Dehez), grenier@lei.ucl.ac.be (D. Grenier), raucent@prm.ucl.ac.be (B. Raucent).

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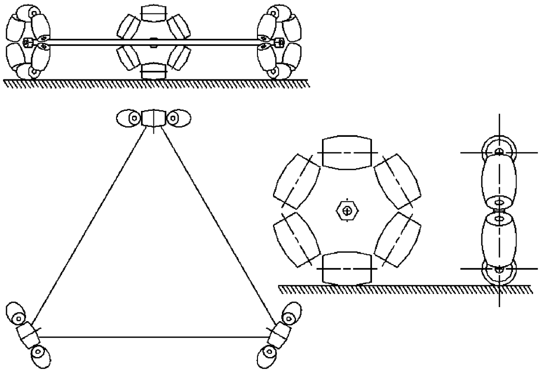

Fig. 1. Omnimobile platform with "universal wheel".

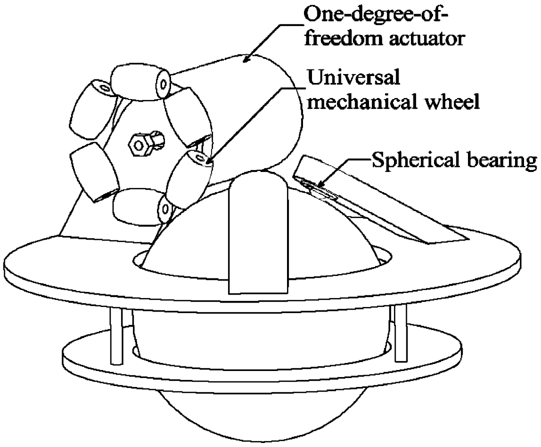

Fig. 2. The ROLLMOBS concept.

successive shocks occurring each time the contact point passes from one roller to another.

In order to limit these drawbacks, our laboratories developed an original prototype called ROLLMOBS [2,3,8,9]. The principle is to uncouple the drive and load-carrying functions by placing a spherical wheel between the universal wheel and the ground, as illustrated in Fig. 2. The performance of the structure (load capacity, surmountable bump height,...) now depends on the sphere diameter and no longer on the roller diameter.

Another interesting solution proposed by West and Asada [1] uses spherical wheels in combination with roller systems. This solution increases the load capacity as does ROLLMOBS but in addition does not generate vibrations. However, part of the motion transmitted to the spherical wheel by the roller systems is lost in friction, which reduces the overall performance of the solution.

To revert to ROLLMOBS, the limitations of mechanical universal wheels, which generate undesirable vibrations, led us to the new idea of developing an electrical actuator having the same capabilities as the mechanical universal wheel (two DOF with at least one being motorized). Indeed, this actuator, used as an electrical universal wheel, could advantageously replace the mechanical universal wheel, as illustrated in Fig. 3. The use of a spherical wheel between the actuator and the ground is maintained in order to protect the actuator from dirt and to increase friction between ground and actuator. It also allows us to use an electrical actuator with a smaller diameter, without reducing the surmountable bump height, and thus, its rotor being essentially made of metal (copper and iron), to decrease the weight.

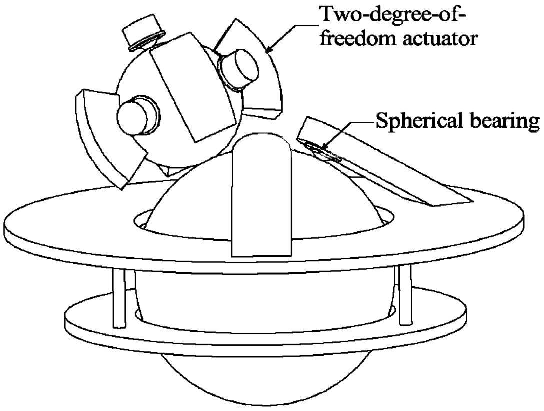

Fig. 3. Use of the two-DOF spherical actuator as an electrical universal wheel.

This paper presents the design of such a spherical actuator with several DOFs and unlimited angular range. The first design stage, which led us to a well-defined electromagnetic concept, is presented in Section 2. The second stage, explained in Section 3, is the modeling. This should allow us to predict the actuator behavior and then to size it following the needs. The third stage is the manufacture of a first one-actuated-DOF prototype with a view to validating the concept and the various models through experiments. This is presented in Section 4. Finally, in Section 5, we present the test bench and the first experimental results.

2. Electromechanical design

Among the various electromechanical conversion principles (piezoelectric, electrostatic, electromagnetic, …), we chose the electromagnetic one because of the power range envisaged for our actuator, above a few watts. Within this actuating family, we opted for the induction principle rather than synchronous and variable-reluctance ones [10,11]. The main justification of this choice is simplicity. Indeed, to operate, synchronous and variable-reluctance motor supplies need to be synchronized with the rotor position. Induction motors, conversely, can operate in an open loop and do not require a spherical positioning system.