DESIGN AND DEVELOPMENT OF AN ORIENTATION SYSTEM FOR A MOBILE MANIPULATOR TO BE UTILIZED IN MICROGRAVITY APPLICATIONS

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Abdulkadir KABUL, Alperen ARICI, Tamer YARDIMCI

Supervisor: Assoc. Prof. Dr. Erkin GEZGİN

MEE DEPARTMENT OF MECHATRONICS ENGINEERING

Abstract

Parallel to the increase in outer space operations, studies that try to implement robotic systems into applications executed in microgravity environment gains popularity in near era. Due to the limited human resources and challenging environments in outer space, various robot manipulators have been designed to accomplish both collaborative tasks and autonomous tasks along with the humans. On the other hand, there still exist many challenges in the field waiting to be solved. One of these can be given as providing locomotion to the mobile robotic systems that will be utilized in microgravity environment as the task is totally different from conventional approaches taken in land or air operations. In light of this, current study tries to propose an orientation system that can be implemented on a mobile manipulator to provide rotational locomotion. The system mainly utilizes a rotating flying wheel and two degrees of freedom spherical parallel manipulator to implement conservation of angular momentum to the given locomotion task.

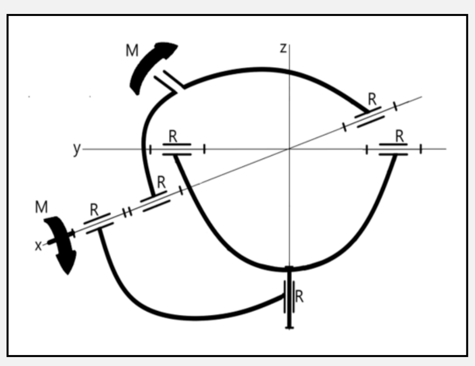
1. Introduction

In microgravity environments, it is very difficult to achieve desired motions because of the environmental limitations, where friction forces and robots can not efficiently react. For this reason, various methods have been proposed to provide locomotion in the past and present. For example, The Spheres [1] are able to move in micro-gravity environment with 6 degrees-of-freedom, using twelve cold-gas thrusters that use liquid CO_2 as propellant. An electro-mechanical fan system is used to provide movement in Astrobee [2], another variation of the mobile system. Proposed system consists of three cubed-shaped robots, software and a docking station used for recharging. Astrobee uses electric fans as a propulsion system that allows flying freely through the microgravity environment of the station.

The main purpose of current project is to provide orientation motions in microgravity environments by a different approach utilizing rotating flying wheel and 2 DoF spherical parallel manipulator [3]. Presented system provides orientation motions under the law of conservation of angular momentum. In this scenario, existing fly wheel connected to the main platform of the manipulator rotates at a fixed angular speed. Exerting any torque to this platform from the manipulator actuators, direction of angular momentum changes towards given torque and the body of the system starts its orientation movement. Controling the torques it is possible to orient the system in a desired manner.

2. Structural Design

Kinematic representation and mobility calculation of the selected 2 DoF spherical parallel manipulator can be seen below.



$M = \sum f_i - \sum \lambda$ **(1)**

$\sum f_i$ *:* the total DoF of all kinematic pairs in the system, $\sum \lambda$ *:* the total subspace of the, independent loops of system, *M: Mobility* [4]

$\sum f_i = 5$, $\lambda = 3$, $M = 2$

Figure 1: Kinematic Representation and Mobility Calculations

3. Theoretical Calculations

Quaternion Algebra is utilized for the direct task of the manipulator. Position of the platform and the direction of angular momentum can be calculated as $\hat{L}_f$;

$$\hat{L}_f = q_1 q_2 (\hat{k}) q_1^{-1} q_2^{-1} \text{ (2)}$$

where, $q_1 = \cos\left(\frac{\theta}{2}\right) + i \sin\left(\frac{\theta}{2}\right), q_2 = \cos\left(\frac{\theta}{2}\right) + j \sin\left(\frac{\theta}{2}\right)$. The net torque on the system can be calculated as the change of angular momentum;

$$\tau = dL/dt,\ dL = \tau dt \text{ (3)}$$

if the net torque is not zero, precession velocity that will generate the rotation θ of the mobile manipulator in microgravity becomes,

$$\Omega = d\theta/dt,\ d\theta = dL/L \text{ (for small angles)},\ \Omega = \tau / L = \tau / Iw \text{ (4)}$$

where, w is the angular velocity of the flying wheel, I is the inertia and L is the angular momentum.

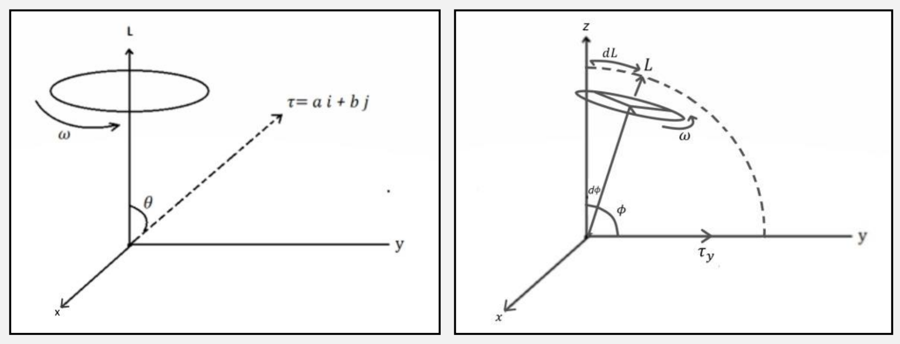


Figure 2: Change in Orientation due to Applied Torque

4. Experimental Setup

3D model of the proposed system was designed in CAD software prior to the prototype manufacturing.

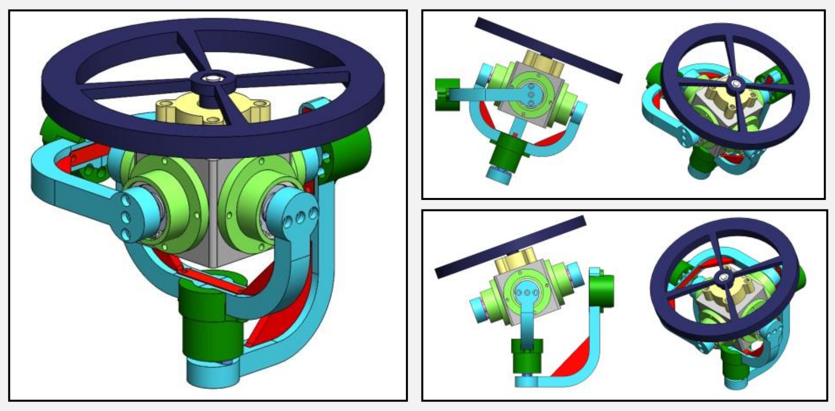


Figure 3: 2 DoF Spherical Manipulator Proposed for the Orientation System

In order to carry out hardware verification to simulate the behavior of the system in microgravity, a planar force plate was designed.

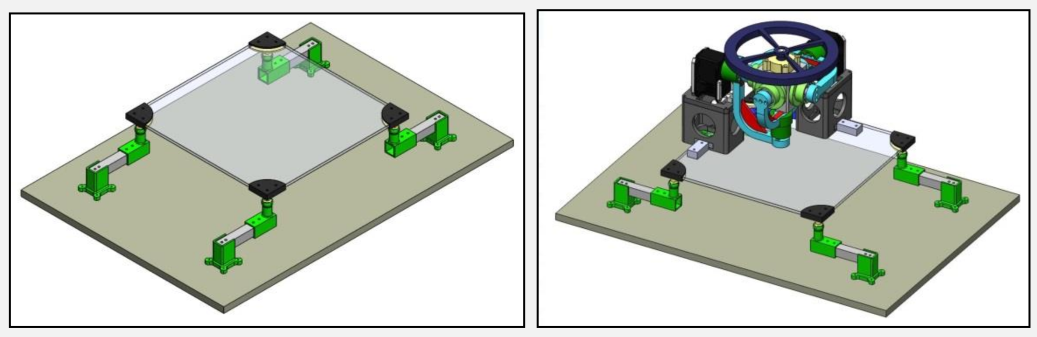


Figure 4: Designed Force Plate and Overall Assembly

Four distinct load cells were placed to the corners of the plate that will behave as the base of the manipulator. From this point forward, first prototype of the system was manufactured and assembled with respect to the designed CAD model.

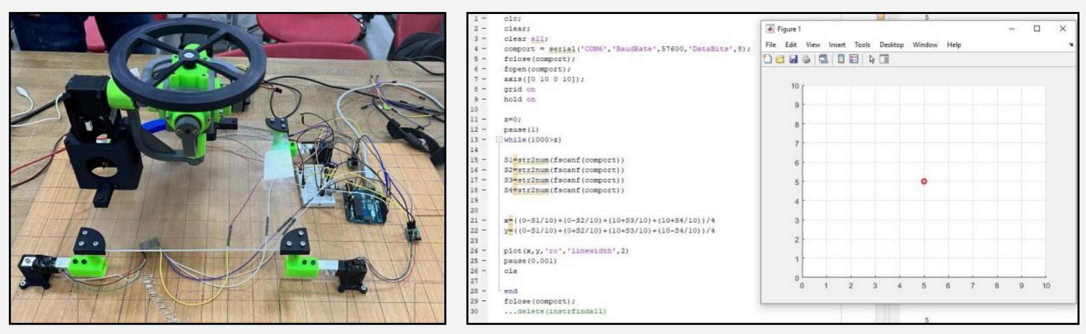


Figure 5: Experimental Setup and the Calibration

After the calibration of the sensors, center of the mass of the experimental system was ofsetted to the geometric center of the plate. During the experiments shift in the center mass was observed with respect to the applied torques through the actuators that successfully verified proposed case. Under microgravity where no fixed base present, observed shift will cause the body of the manipulator orient.

4. Conclusions

In this project, relationship between angular momentum and applied torque was utilized. It is theoretically confirmed that a mobile robot designed for microgravity environment can change its orientation via the proposed methodology. All of the verifications and calibrations were carried out on MATLAB environment.

Future works of the study will include the addition of balancing system to negate the effects of rotating flying wheel to controll remaing independent orientation of the mobile manipulator. Following this translational locomotion will be studied and implemented to the system. In early considerations a fan system similar to the one in Astrobee was decided to be utilized. This fan system can be provided with a single fan and the control of the air channels. Also simulations of the overall system will be carried out in a virtual environment where physics are applicable like Unity3D.

References

[1] The SPHERES Guest Scientist Program (PDF), Mark O. Hilstad, John P. Enright, and Arthur G. Richards Swati Mohan, 2010-01-05.

[2] Astrobee Guest Science Guide PDF, National Aeronautics and Space Administration, 2017-08-31.

[3] Gosselin, C. M., Pierre, E. S., & Gagne, M. (1996). On the development of the agile eye. IEEE Robotics & Automation Magazine, 3(4), 29-37.

[4] F.Freudenstein, R.Alizade, On the degree of freedom of mechanisms with variable general constraint, IV World IFToMM Congress, England,(1975).