Vibration isolation in spacecraft using Gough-Stewart Platform

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1 Introduction

In spacecraft, micro-vibrations (up to 300 Hertz) induced due to the presence of reaction wheels, momentum wheels, and cryocoolers, reduces the pointing accuracy of sensitive payloads mounted on it. A 6 degree of freedom Gough-Stewart platform (GSP) is effective for isolating payloads from these micro-vibrations. It is known that a conventional Gough- Stewart platform fails to give dynamic isotropy where the first six vibration modes have the same or nearly the same natural frequency. The primary reasons to use dynamically isotropic GSP are a) it is easy to tune dampers for passive vibration attenuation for the given frequency bandwidth, and b) a multi-input-multi-output system system can be treated as six decoupled single-input-multi-output systems (for six degrees of freedom), which simplifies active control.

A **two radii or Modified Gough-Stewart Platform (MGSP)** is proposed to achieve dynamic isotropy. An MGSP is a parallel manipulator with a movable top platform, a fixed base, and struts with a linear actuator in between them. It differs from the traditional GSP with the anchoring points/spherical joints are on two radii on each platform instead of on one radius in a traditional GSP, as shown in Fig. 1(a). In an MGSP, these struts are divided into two sets having a rotational symmetry for their attachment points along the circumference with an equal angular spacing of 120°.

2 Design of MGSP

The unknowns (design parameters) for an MGSP are the inner and outer radii of the bottom and top platforms, R_{bi}, R_{ti}, R_{bo}, R_{to} the angular separation of the connection points in the top and bottom platform (inner and outer), $\alpha_{to}, (\alpha_{bi} - \alpha_{ti})$, the leg length ratio a, and the height of the top platform H from the bottom platform (see Fig. 1a). The force transformation matrix ($[\mathbf{B}]$), together with a novel *geometry-based approach*, is used to obtain closed-form analytical solutions in their explicit form for dynamic isotropy in a 6-6 MGSP at its neutral position. For dynamic isotropy, the six eigenvalues of the natural frequency matrix $[\mathbf{G}]$ [1] must be equal.

$$[\mathbf{G}] = [\mathbf{M}]^{-1}[\mathbf{K_T}] = [\mathbf{M}]^{-1}k[\mathbf{B}][\boldsymbol{B}]^T \quad (1)$$

where $[\mathbf{M}]$ is the mass matrix of the payload, $[\mathbf{K_T}]$ is the stiffness matrix in the task

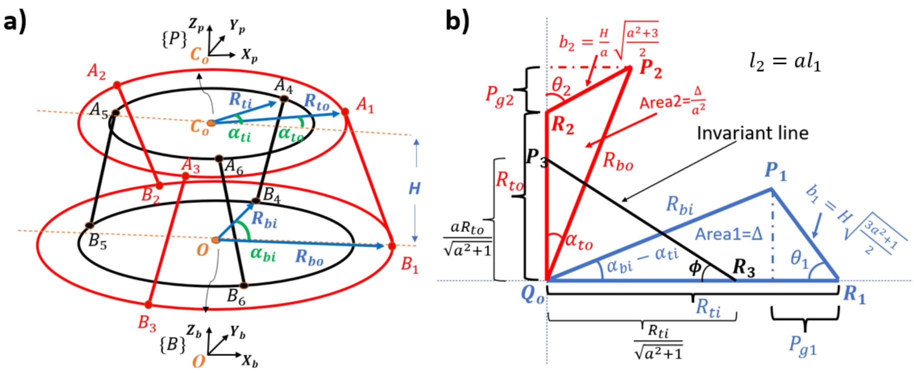

Fig. 1. **a)** MGSP, **b)** Geometrical interpretation of MGSPs' design variables [1]

space, and k is the axial stiffness of each strut. The obtained set of transcendental equations from equal eigenvalue conditions lead to several geometrical observations from where closed-form solutions to the design variables were developed [1] – a 3-D dynamically isotropic MGSP design problem could be simplified into sets of triangles in 2-D space related by certain geometrical relationships (refer to Fig. 1(b)) that can be used to find the design variables.

3 Validation via simulation and experiments

A prototype based on flexural joints (refer to Fig. 2) was developed for experimentation (to avoid friction and backlash in the spherical joints), and various flexural joints were explored before arriving at the final design. All six natural frequencies obtained analytically from Section 2 match well with simulation results -- validating our design. We were able to capture the first six modes experimentally lying in a narrow frequency bandwidth around 29 Hertz, which were very close to analytical and simulation results. The platform is designed for approximately 10.5 Kg payload including the mobile platform and can isolate micro vibration above 41 Hertz.

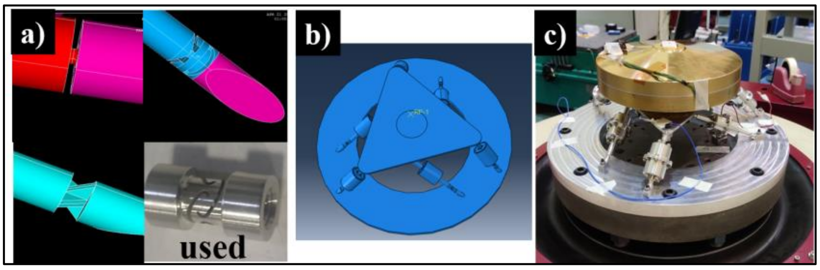

Fig. 2. **a)** Various flexural joints explored, **b)** CAD model, **c)** Experiment prototype of MGSP

References

1. Singh, Y.P., Ghosal, A.: Dynamically isotropic Gough-Stewart platform design using a pair of triangles. In: Proc. of 32nd International Conference on Robotics in Alpe-Adria-Danube Region, Springer Nature, Bled, Slovenia (2023, Accepted).