A method for attitude control of telescopes making use of the reverse pendulum

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National Astronomical Observatory Mizusawa has developed a telescope with the focal length of 1m and diameter of 0.1m to be set on the Moon for observation of lunar rotation. It is essential to make a much small and light one to meet the requirement from smaller rockets which is a new trend in lunar and planetary explorations in Japan. We propose a new method to control the attitude of the tube by making it to be a reverse pendulum.
A tube supported by a single point at the bottom looks unstable, but it is possible to control the attitude with high sensitivity because it tends to fall down even if it slightly deviates from the vertical. We put a tube with a conical bottom on a XY stage, and surround the top of it by a ring putting 4 pressure gauges between them (Fig. 1). If the tube deviates from the vertical direction, a force acts on the pressure gauges. Then we move the bottom of the tube horizontally until the force becomes zero, and the tube is kept to be vertical. This attitude control does not restrict the optical system of the telescope because any optical element as the horizontal reference plane like a mercury pool is not necessary, nor nothing comes in the field of view.
When a reverse pendulum with the mass m (kg) deviates from the vertical direction by angle θ, the force P acting horizontally is represented as $P = mg\sin\theta$. If we suppose m = 1 kg, θ= 1 arc second (4.8×10^{-6} rad), P becomes 10^{-5} N (about 50 μN). We can detect the force of 0.005mN which is about 1/10,000 of the force in the case of 1 arc second if we use the most sensitive pressure gauge. This means that we can control the attitude of a tube with the sensitivity of 0.1 milli-arc second.
On the other hand, it has the dynamic range of 20,000 times as large as the resolution, thus the most sensitive sensor has the range of 20 μN. Therefore, we must keep the tube within 20 arc seconds of the vertical direction in some other way.
As to the XY stage, it needs to have a sensitivity of 5×10^{-10} m (0.5 nm) in order to control the verticality within 1 milli-arc second. It is not impossible if we utilize a certain reduction mechanism or an inchworm.
This method can open the new way in the future mission with a small and light telescope for observation of rotation on the Moon or on the planet.

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