

# Control of Tetherless Magnetic Devices using Multiple Synchronously Rotating Permanent Magnets

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Small-scale tetherless magnetic devices (TMDs) have great potential value in the biomedical field since they can be functionalized with multiple abilities such as micro-object transportation, microfluid manipulation, and overcoming biological barriers. To realize these abilities, the controllable motion of TMDs is desirable. The permanent magnet-based actuation system is a viable option to actuate a TMD in viscous and viscoelastic media. The instant forward and inverse model between the dipole-rotation axis and the field-rotation axis is crucial to implement the motion control of TMDs. This model has been demonstrated with the actuation systems based on a single rotating permanent magnet. However, the actuation systems based on a single rotating permanent magnet generate undesirable gradient force causing lateral oscillations to TMDs. These oscillations can be mitigated with the actuation systems based on multiple synchronously rotating permanent magnets. We establish that instant forward and inverse model to the systems based on multiple synchronously rotating permanent magnets. To verify the proposed model, we implement the motion control of a TMD with the system based on two synchronously rotating permanent magnets. The experimental results demonstrate that the maximum positioning error of three-dimensional motion control is 5.29 mm.