Interaction with Virtual Environments via a Kinesthetic Mid-Air Haptic Device and Augmented Reality

Mina M. Micheal[1,2], Alaa Adel[2], and Islam S. M. Khalil[1]

***Abstract*— The integration of magnetic haptic feedback and augmented reality (AR) holds promise for several applications such as entertainment, medical training simulators, and minimally invasive surgery. A magnetic force is wirelessly generated using an electromagnetic-based haptic interface to render a three-dimensional (3D) virtual object, whereas AR deploys its virtual image over other real-world objects. An interactive demonstration combining visual and haptic feedback provides a proof-of-concept as an efficient method for rendering volumetric objects in mid-air. This integrated haptic AR interface represents an effective component of a wider HCI platform.**

I. Introduction

Augmented reality (AR) has gained immense popularity in recent years owing to its various applications ranging from entertainment, education, manufacturing to medical training simulators [1]. Mid-air haptics is an emerging technology that can enhance interaction in virtual environments by providing haptic perception at a distance. Mid-air electromagnetic-based methods provide haptic feedback by applying controlled magnetic forces on a dipole attached to a wearable finger splint [2]. In our previous study, an electromagnetic-based haptic interface (EHI) is developed to render virtual objects in mid-air [3]. We observe that the success rate in object differentiation is limited due to the absence of any visual feedback between the participant and the virtual object. Visual feedback is particularly valuable as it guides the participant to the boundaries and limits the workspace of the participant to the region of the object.

II. System

Integration of magnetic rendering and AR enables a participant to interact with virtual objects in mid-air (Fig. 1). The system is composed of the following subsystems: (1) an array of nine electromagnetic coils; (2) a wearable finger splint with a magnetic dipole; (3) a head-mounted display; (4) position sensing device to decouple haptic rendering from visualization (5) control algorithms. Magnetic forces are exerted to mimic the boundaries of a virtual object deployed over the EHI and programmed into a head-mounted display (Hololens, Microsoft Corporation, USA). In the AR scene, the user is asked to interact with a virtual orange in mid-air.

III. Magnetic Rendering

Rendering 3D virtual objects in mid-air requires perception of the volumetric properties of object. The constraint surface of the virtual object is extracted from its CAD model, and discretized into point cloud. Each point is mapped into constraint force using $\mathbf{F_s} = \lambda \nabla g(\mathbf{r}, t)$, where $\mathbf{r} \in \mathbf{R}^{3\times1}$ is the position of a point on the constraint surface $g(\mathbf{r}, t)$ and λ is a force constant that maps the object's geometry to the force capabilities of the EHI. The force exerted on a dipole ($\mathbf{m} \in \mathbf{R}^{3\times1}$) at a point $\mathbf{p} \in \mathbf{R}^{3\times1}$ in a controlled field $\mathbf{B}(\mathbf{p}) \in \mathbf{R}^{3\times1}$ is $\mathbf{F_m} = \sum_{i=1}^{n} \nabla(\mathbf{m} \cdot \tilde{\mathbf{B}}_i(\mathbf{p})) I_i$, where $\tilde{\mathbf{B}}_i(\mathbf{p})$ is the magnetic field current mapping and I_i is the input current to the ith electromagnetic coil. We use the following objective function to calculate the current inputs to the EHI:

$$\begin{aligned} \underset{\mathrm{I}}{\text{minimize}} \quad & \epsilon(\mathbf{I}) = \|\mathbf{F_s} - \mathbf{F_m}\| \\ \text{subject to} \quad & 0 < I_i \le u_i, \quad i = 1, \ldots, n \\ & \sum_{i=1}^{n} I_i \le I_{\mathrm{t}}, \quad i = 1, \ldots, n, \end{aligned} \tag{1}$$

where $\epsilon(\mathbf{I})$ is the objective function to be minimized. Further, u_i is an upper-limit on the input current and I_t is the maximum current provided via a power source.

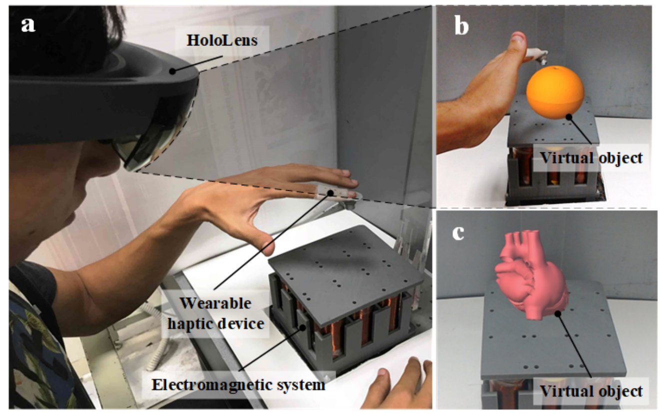

Fig. 1. Visual feedback is provided via a head-mounted display. The constraint surface of the object is rendered using magnetic forces.

References

[1] C. Bermejo and P. Hui, "A Survey on Haptic Technologies for Mobile Augmented Reality," ACM Computing Surveys, 184 (Dec 2022).

[2] A. Adel, M. A. Seif, G. Hölzl, M. Kranz, S. Abdennadher and I. S. M. Khalil, "Rendering 3D virtual objects in mid-air using controlled magnetic fields," IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), (Sep 2017).

[3] A. Adel, M. M. Micheal, M. A. Self, S. Abdennadher and I. S. M. Khalil, "Rendering of Virtual Volumetric Shapes Using an Electromagnetic-Based Haptic Interface," IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS),(Sep 2018).

[1]Department of Biomechanical Engineering, University of Twente, 7522 NB Enschede, The Netherlands. e-mail:i.s.m.khalil@utwente.nl

[2]HapMag BV, 7557 BK Hengelo, The Netherlands.