MagneLayer: Force Field Fabrication for Rapid Prototyping of Haptic Interactions

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ABSTRACT

Magnets are very useful for the rapid prototyping of haptic interactions. However, it is difficult to arrange fine and complex magnetic fields rapidly. This project presents a method for fabricating complex geometric magnetic patterns by overlaying magnetic rubber sheets. By layering multiple magnetic sheets that have proper thicknesses and simple magnetic patterns, various types of magnetic lattice patterns can be generated on the top surface. Furthermore, the superposed magnetic fields can be changed dynamically by rotating the layered magnetic sheets. We demonstrate several tactile interactions by applying the superposed magnetic fields.

CCS CONCEPTS

• **Human-centered computing → Haptic devices**; *User interface toolkits*; *Interface design prototyping*.

KEYWORDS

Magnet; tactile; haptic; rapid prototyping; DIY; fabrication

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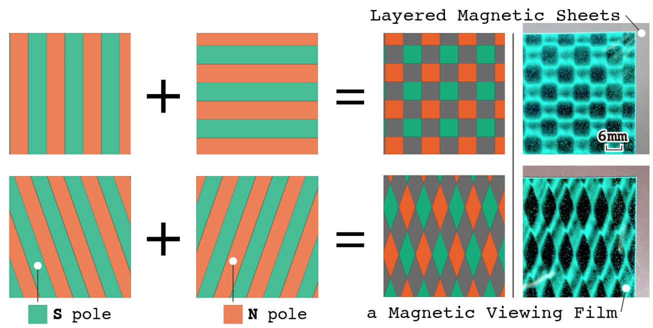

Figure 1: Examples of superposition of magnetic patterns and pictures of superposed magnetic fields.

1 INTRODUCTION

The barriers to making things have become much smaller than ever. We can create various kinds of things using a 3D printer and a laser cutter. However, human-computer interaction (HCI) researchers are still exploring new ways to make processes faster, easier, and cheaper [Baudisch 2016].

Tactile technologies are no exception in this rapid prototyping trend. Many prototyping methods of tangible objects that have unique textures [Ion et al. 2018; Takahashi and Miyashita 2016], or that have magnetic force-based tactile feedback [Liang et al. 2014; Ogata 2018; Zheng et al. 2019] have been proposed. Among them, tactile design approaches that use magnetic rubber sheets are good for prototyping [Yasu 2017, 2019] because magnets do not require any power supply for providing haptic stimuli. Just a pair of magnetic strips with specific magnetic patterns can present various tactile stimuli when they are rubbed together. However, it has not been possible to magnetize complex geometric patterns rapidly. Therefore there are limitations on rapid prototyping of haptic interactions that use complex magnetized patterns.

So, we solved the trade-off between the rapidity and complexity of magnetization by overlaying multiple magnetic rubber sheets containing simple magnetized patterns (Figure 1).

2 BASIC PRINCIPLES

To simplify the calculation, we assume the simplest situation, where two cylindrical magnets (upper magnet 1 with radius R and thickness t_1 and lower magnet 2 with radius R and thickness t_2) are stacked. Using this model, the magnetic flux density B at the center of the top surface of the stacked magnets can be estimated by the following formula [Camacho and Sosa 2013]:

$$B = \frac{Br}{2}\left(\frac{t_1}{\sqrt{R^2 + t_1^2}} - \frac{t_2 + t_1}{\sqrt{R^2 + (t_2 + t_1)^2}} + \frac{t_1}{\sqrt{R^2 + t_1^2}}\right) \tag{1}$$

Br is residual magnetic flux density, which is determined by the magnetic material. Applying this formula (1), the best thicknesses to balance the magnetic forces of the two stacked magnets can be calculated as bellow.

$$t_2 = -t_1 + \frac{2t_1 R}{\sqrt{R^2 - 3{t_1}^2}} \quad (R^2 - 3{t_1}^2 > 0) \tag{2}$$

Although the cylindrical model is not exactly the same as the practical situation, the requirements for the thicknesses t_1 and t_2 can be derived with ease using this equation. In Figure 2, the balancing thicknesses of the magnetic sheets for superposition are visualized so that the user can refer to them.

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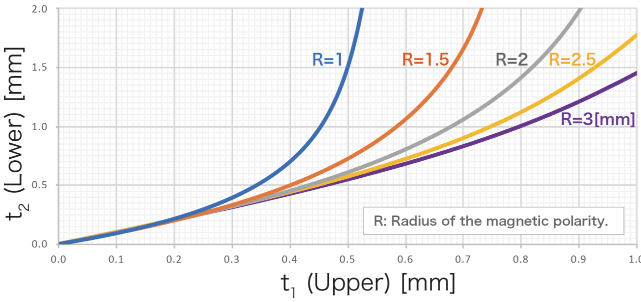
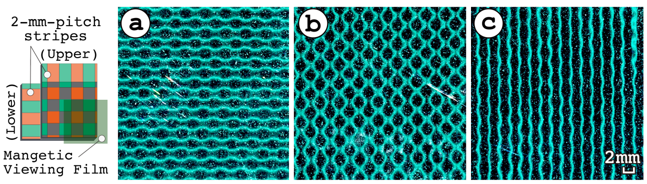


Figure 2: A graph from the derived equation. The best balancing thicknesses for magnetic superposition can be seen as references.



	a	b	c
t_1 (Upper)	0.31 mm	0.51 mm	0.82 mm
t_2 (Lower)	1.52 mm	1.52 mm	1.52 mm

Figure 3: When the thicknesses of the two magnetic sheets match the derived values, a clear checkered pattern can be seen (b). However, when the upper sheet is too thin (a) or too thick (c), only distorted stripe patterns are seen.

Based on the above principles, when the thicknesses of both sheets match the derived thickness, a clear checkered pattern can be seen (Figure 3, b). However, when the upper sheet is too thin (Figure 3, a) or too thick (Figure 3, c), only a distorted stripe can be seen on the magnetic viewing film. These results support that a checkered magnetic pattern can be constructed under the conditions derived from the equation.

3 APPLICATION

Our method allows users to design, make, and modify haptic interactions rapidly. Even large magnetic sheets can be quickly magnetized using a hand-held magnetizer, and the spatial frequency of the superposed magnetic pattern can be changed by the relative angle of the two magnetic sheets (Figure 4 a). Therefore, for example, creators can change the haptic feedback many times to fit games, tools, and body-scale interactions (Figure 4, b and c). Further, by combining this method with other interactive techniques, there will be more creative possibilities.

Figure 4: Application examples. The rotating structure allows tactile feedback to be modified without re-magnetization (a), and the haptic feedback for games and body-scale interactions can be prototyped rapidly (b and c).

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