Demonstration of Mixels: Fabricating Interfaces using Programmable Magnetic Pixels

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1 ABSTRACT

In this demonstration, we present Mixels, programmable magnetic pixels that can be rapidly fabricated using an electromagnetic printhead mounted on an off-the-shelve 3D printer. The ability to program a magnetic material pixel-wise with varying magnetic forces enables Mixels to create new tangible, tactile, and haptic interfaces. To facilitate the creation of interactive objects with Mixels, we provide a user interface that lets users specify the high-level magnetic behavior and that then computes the underlying magnetic pixel assignments and fabrication instructions to program the magnetic surface. Our custom hardware add-on based on an electromagnetic printhead clips onto a standard 3D printer and can both write and read magnetic pixel values from magnetic material. Finally, we highlight the importance of fundamental magnet parameters such as coercivity and remanence in designing a magnetic plotter, and show how leveraging 2D plotting enables a number of interactive applications.

2 INTRODUCTION

Advances in digital fabrication tools have enabled users to fabricate objects with a wide range of properties by modifying physical parameters, such as the color [13], surface texture [14], and compliance [4, 7] of objects. More recently, digital fabrication tools have also been used to fabricate objects with other functional properties, such as custom acoustic [2] and optical [17] behaviors.

Magnetic materials, however, still remain far behind this digital fabrication revolution [3] despite the fact that magnetic materials hold great promise for interactive applications. For example, researchers used magnets to create novel tangible interfaces (*MechaMagnets* [18]), to produce custom tactile sensations (*MagneLayer* [16]), to guide the assembly of 3D objects (*DynaBlock* [12], *ElectroVoxel* [6], *Stochastic Self-assembly* [5]), and to create actuated interfaces (*Programmable Polarities* [10]). However, all of these works either use off-the-shelf magnets (*MechaMagnets* [18], *DynaBlock* [12]) or require manual construction of the customized magnetic materials (*FluxPaper* [11], *MagneLayer* [16]).

More recently, researchers also started to automate the fabrication process of custom magnetic materials. For instance, *Magnetic Plotter* [15] is a 2D plotter that stamps custom magnetic patterns onto magnetic sheets using two permanent magnets to provide interaction. Although this method supports programming a variety of patterns, *Polymagnets* [1] introduced a commercial product that expedites the programming of magnetic pixels and developed a method to create magnets with unique applications such as non-contact attachment. However, researchers have not yet investigated how to create a design and fabrication pipeline for programmable magnetic pixels that are selectively attractive, repulsive and agnostic between multiple objects.

In this demonstration, we introduce Mixels [8], the first digital fabrication pipeline for arbitrary 2D magnetic patterns through programmable magnetic pixels, which we call Mixels. In contrast to prior work, which only showed how to create repeated patterns across magnetic material, our system is able to create arbitrary 2D binary patterns (North "N" or South "S" poles) on the magnetic sheet with high precision. We use this feature to synthesize patterns of N- and S-polarized pixels that exhibit selectivity to other faces in some orientations, while exhibiting agnosticism (i.e. not interacting magnetically) in other orientations. We accomplish this

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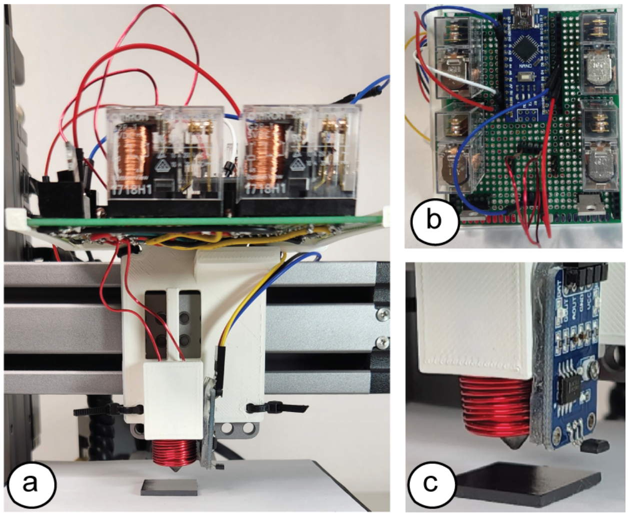

Figure 1: Magnetic plotter. (a) plotting add-on mounted onto a 3-axis CNC. (b) add-on electronics viewed from above. (c) Zoom of the plotting end effector, consisting of an cone-tipped electromagnet for writing and a hall effect sensor for reading magnetic programs.

by evaluating the 2D cross-correlation between the matrices representing these pixel patterns and choosing only those matrices that maximize mutual agnosticism between pairs [9]. Finally, our system can vary the magnetic force of Mixels continuously (N to S) rather than just discreetly (N or S).

Mixels hardware (Figure 1) consists of a custom magnetic plotter to stamp the soft magnetic sheet. The plotter includes an electromagnet for writing magnetic pixels, a hall effect sensor for reading them, and auxiliary electronics, installed in a housing mounted onto a 3-axis CNC. Mixels software interface allows the user to create encoding patterns, which on export are translated into fabrication instructions, allowing the plotter to program magnetic faces without manual intervention. We demonstrate how the programmed magnetic material can be easily integrated into various objects for prototyping of tangible, tactile, and haptic interfaces.

3 APPLICATIONS

We built a number of applications to demonstrate features of the system. Figure 2 shows how objects can be programmed magnetically to exhibit unique force profiles. Three magnetic faces have been programmed and affixed to the bottom of 3D-printed objects; they are marked with green, yellow and red labels. When each of these is placed on a platform housing a pressure sensor, the unique force profile is registered by an Arduino and the associated colored LED lights up.

Figure 3 shows how attachments to objects can be programmed that only permit placing objects in unique orientations and locations. We adhere specially formulated magnetic patterns with double sided tape to a workshop wall and their paired complements to associated tools; the tools will only bond when placed on the associated correct location on the workshop wall and in the correct orientation. Locations and orientations can both be reprogrammed.

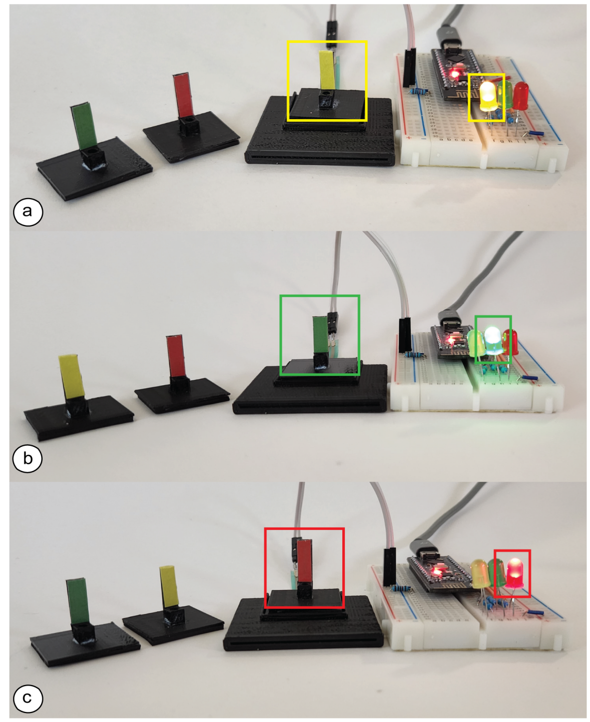

Figure 2: Invisible tagging and detection of objects using selectively attractive patterns.

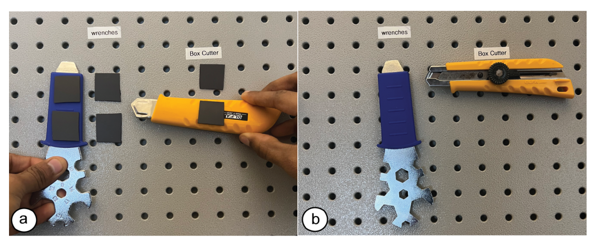

Figure 3: Storage of objects that will only adhere to a workshop wall in particular locations and orientations.

Figure 4 shows how magnetic patterns can be plotted to create selectively paired locks and keys. Mating pairs of specially formulated magnetic patterns based on orthogonal codes are found on the keys (foreground) and locks (background); for example, the yellow key opens a lock to the hidden yellow surface, but not others. Keys can be programmed to open multiple locks, and vice versa, and both locks and keys can be quickly reprogrammed for new security requirements. Moreover, unlike physical keys, the structure of the magnetic keys is invisible to the naked eye.

Figure 5 shows how magnetic patterns can be used to create self-assembling or self-guided assembly techniques guided by magnetically programmed instructions. We can program arbitrary textures onto sheets (as with a magnetic drawing board) and view these

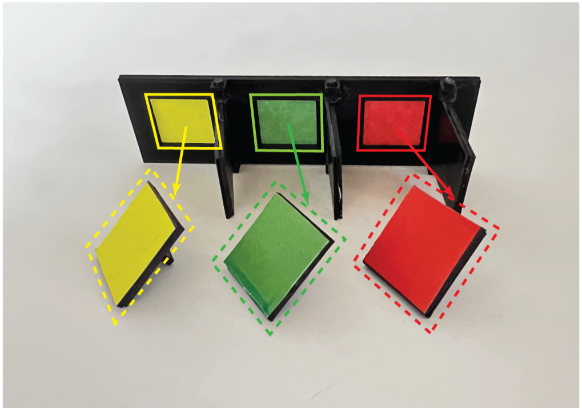

Figure 4: Selectively magnetic lock-and-key systems. Colored locks (solid lines) mate with keys of the associated color (dashed line), but not others.

using magnetic viewing film adhered onto its surface. We adhere these laminates to cubes, program letters onto their top faces, and program selectively mating patterns on faces *between* cubes. The result is that the cubes adhere magnetically only when assembled correctly to form a word, and cannot be assembled in any other anyway.

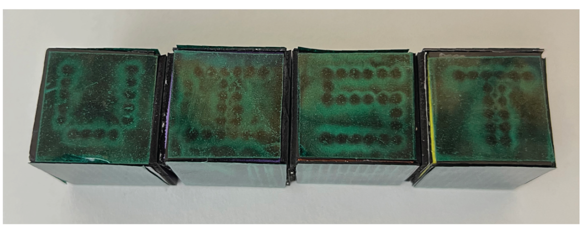

Figure 5: Arbitrary textures printed in tandem with selectively attractive faces guides users haptically to assemble objects in a single correct configuration.

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