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# Animating Matter: Creating Organic-like Movement in Soft Materials

## **Iddo Wald**

Media Innovation Lab  
School of Communication  
IDC Herzliya  
Herzliya, 46150, ISRAEL  
iddo.wald@milab.idc.ac.il

## **Yoav Orlev**

Media Innovation Lab  
School of Communication  
IDC Herzliya  
Herzliya, 46150, ISRAEL  
yoav.orlev@milab.idc.ac.il

## **Andrey Grishko**

Media Innovation Lab  
School of Communication  
IDC Herzliya  
Herzliya, 46150, ISRAEL  
andrey.grishko@milab.idc.ac.il

## **Oren Zuckerman**

Media Innovation Lab  
School of Communication  
IDC Herzliya  
Herzliya, 46150, ISRAEL  
orenz@idc.ac.il

## **Abstract**

Shape-changing materials development strives to generate motion in new ways, extending the traditional motor-based and mechanism-based techniques. We present a system that uses continuous magnetic force to create movement in a range of soft materials such as textile, foam, paper or silicon. The system has two parts: a control platform and a multi-material layer. The control platform is an array of electromagnets controlled by a microcontroller. The multi-material layer is made of a soft material with embedded ferromagnetic elements. The subtle electromagnetic force manipulates the embedded ferromagnetic material, resulting in continuous and organic-like movement in the material layer. We hope our system can empower designers to generate expressive movement with a broad range of materials. In our own work, we aim to extend our Empathy Objects research with soft materials, creating physical objects that convey emotion through expressive movement.

## **Author Keywords**

Shape Change, Tangible User Interface, Soft Material, Empathy Objects.

## **ACM Classification Keywords**

H.5.2 Information Interfaces and Presentation: User Interfaces.

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Figure 1: Material experimentation. From the top: fluted foam, Tyvek, plastic and textile. Each with 4 magnets. Some include acrylic disks added to accentuate the form.

## Introduction

As HCI researchers we always look for new ways to enrich human computer interactions. Engelbart and Sutherland pioneered the field with a human-centered approach to technology that emphasizes the human experience. Buxton, Fitzmaurice and Ishii [2] presented the vision of physical-digital interaction with Bricks, an interactive projection-based surface. Ishii and Ullmer continued this work with the Tangible Bits vision [6], defining the field of Tangible User Interfaces (TUI), and laying out three main categories of TUI: interactive surfaces, coupling bits and atoms, and ambient media. Since then HCI researchers have been striving for an even tighter coupling between bits and atoms.

Ishii et al. published in 2012 the Radical Atoms vision paper, laying out the vision for Material User Interfaces (MUI), defined as “Materials that can change form and appearance dynamically”. In the past few years, pioneering work has been done to realize the vision of radical atoms or MUI (see related work). We wish to extend the MUI exploration towards animated matter, and leverage it in our research of Empathy Objects [5], in which we add expressive gestures to non-anthropomorphic robotic objects to convey emotion in general and empathy in particular.

We propose a new system with a magnetic force control platform and a soft material layer (Figure 3), striving to create continuous organic-like movement in soft materials. We hope that using magnetic force will enable smooth, non-discrete looking manipulation, with a non-mechanical nature. Our modular system design enables a range of materials to be used as material layer, from textile with embedded magnets through silicon infused with metal balls to multi-material

mixtures of plastic and magnets (Figure 1). The unique physical properties and internal structure of each material results in different types of movements and behaviors, which we hope will enable new forms of digitally-controlled expressive movement.

## Related Work

### *Shape-change and Material User Interfaces*

Shape-changing interfaces have been introduced in work such as inform [4], Recompose [10] and Transform [7] where motor-based actuators move vertically and form 3D discrete topologies. Jamsheets [11] uses air pressure to stabilize free-formed structures while aeroMorph [8] expands the use of air pressure rather than motors to move between specific pre-defined states. TableHop [13] uses soft fabric manipulated by electrostatic force to create a subtle and gentle interaction which conveys more than data to the user.

### *Magnetic Force Interfaces*

Since the pioneering work of the 2002 Actuated Workbench [12], which used an array of electromagnets for controlling pucks movement on a surface, a growing number of projects utilized magnetic force to generate physical movement. ForceForm [14] uses a similar magnetic grid to the Actuated Workbench, but adds a stretched overlaying silicon surface with an embedded grid of small magnets that can move only in the Z axis, causing subtle pattern changes to be formed. The ZeroN [9] used magnetic force to create a digitally-controlled levitating ball, and BubbleWrap [1] leveraged the same technique to create a shape-changing haptic display.

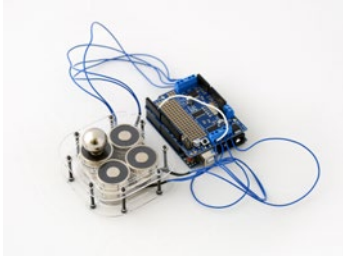


Figure 2: Control platform proof-of-concept prototype. A 2X2 arrangement.

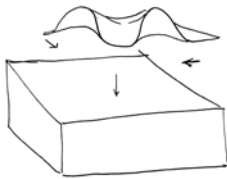


Figure 3: System diagram. A material layer is manipulated using magnetic forces applied by the control platform on the ferromagnetic elements



Figure 4: Actuated material movement in 2D forming a 3D shape in the material layer.

### *Empathy Objects*

We previously defined Empathy Objects [15] as robotic devices that use physical expressive gestures to convey emotion. For example, Kip is a small robotic object reminiscent of a desktop lamp that can extend in a "Curious" gesture or retract in a "Scared" gesture. The expressive movement we designed for our Empathy Objects is limited to motor-based mechanisms. In addition, the current design is highly focused on tangible representation and does not enable direct physical manipulation. Our proposed system strives to extend the Empathy Objects research in two ways: (1) extending the range of soft materials we can use in our designs while controlling their movement to communicate emotion or empathy, without the need for motor-based mechanisms, and (2) enabling gentle physical manipulation with a range of soft materials.

### **Our Approach**

We propose an interface with a shape-changing material layer that produces organic-like movement using continuous magnetic forces. The surface can be manipulated using digital control of electromagnets that enables antialiasing, resulting in a smooth, non-discrete motion. In our current initial prototype, we implemented a control platform using a small array of electromagnets for actuation using magnetic force.

The material layer is a composition of a formable soft material and concentrations of actuated material elements (a magnet or a ferromagnetic material).

As the actuated material is manipulated in 2D, 3D shapes are formed in the soft material. Their form and the movement characteristics are dependent on the

material features, such as thickness and flexibility (Figure 4).

The control platform is capable of sensing the relative location of the actuated material within the material layer, resulting in a two-way interface.

Our unique system design that separates between the non-discrete control platform and the material layer enables experimentation with a large variety of materials and different types of movement. We hope this approach brings us one step closer to organic-like movement.

### **The System**

#### *Control platform*

In the current setup, we use a control platform that is similar to the one presented in the classic Actuated Workbench [12] - an array of electromagnets, applying magnetic force on an actuated material - either magnets or ferromagnetic materials embedded in a soft surface.

Our current proof-of-concept prototype is implemented using 4 off-the-shelf electromagnets (Figure 2). In our next prototype, we plan to use a similar setup to the Actuated Workbench - a 16.5cm (6.5") fixed array of 64 custom-made electromagnets arranged in an 8 x 8 grid under a layer of acrylic.

We control the interface with an Arduino board that clocks each magnet's polarity using a set of octal flip-flops that connect to motor driver chips (H-bridge transistor configuration frequently used for driving electric motors), which in turn control the electromagnets. The strength of each electromagnet's

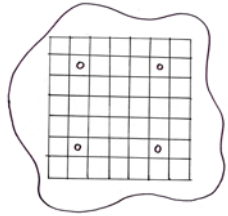


Figure 5: Locations of the actuated material in the material layer.

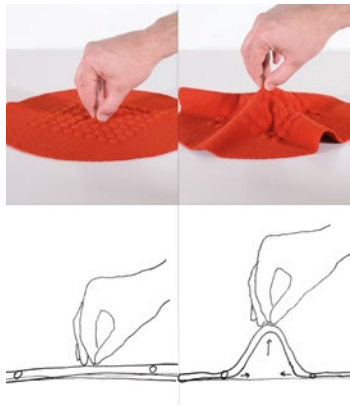


Figure 6: 3D pulling motion on the material layer results in 2D movement of the ferromagnetic elements, allowing sensing and continuously holding in position.

field is controlled through pulse-width-modulation (PWM).

For sensing the location of the magnets, we intend to track the electromagnetic a current. We found that the current created in the electromagnets themselves when moving objects on the surface, could be sufficiently noticeable to use as a sensor.

#### *Formable multi-material layer*

The first material layer we created is made of two layers of textile with 4 embedded magnets. The magnets are positioned so that they can be aligned with the corners of the inner 7x7 magnet array (Figure 5). We added acrylic disks to match the rest of the grid, so to create a uniform appearance and emphasize the shape of the surface formed.

To explore the movement type and behavior of different materials as well as the forces involved, we experimented with additional material layers, including paper, foam and plastic (Figure 1).

Our next steps are to create a variety of silicon layers each with a different hardness level, probably with a lubricant between the surface and control platform to reduce friction.

#### **System capabilities and further system development**

The system in many ways expands the Actuated Workbench ability to create a smooth motion into a 3D space. It also allows for the use of material properties and its construction in designing the interaction. One added benefit of the translation of 2D motion to 3D is the ability to sense a pulling motion and a side motion

(Figure 6), a unique property of this design over most shape-changing systems.

By relying on the material properties and measuring the location of only a few points in the material layer, the system design has an unavoidable inaccuracy level. It is nearly impossible to perfectly predict the exact features of the material movement. While this could prove as a limitation for many applications, we see it as an advantage when the goal is to create organic-like movement that evokes empathy.

#### **Conclusion**

We would like to extend the range of materials that can be used to convey emotion through expressive movement, without the need for motor-based mechanisms. Our proposed system enables experimentation with various materials and structures, and can empower designers to create new interactive experiences. Following are a few of the directions we would like to pursue and experiment with: explore the effect of different types of materials on the behavior of the material layer (for example, with the same electromagnetic force one material might bend while another might wrinkle); create non-homogenous surfaces by shape and texture with less and more flexible parts; add inner "skeleton" structure to define the range of possible forms.

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