Magnetic Table for Levitating Food and Entertainment

Kevin Stanley Bielawski, Nur Ellyza Abd Rahman, Azhri Azhar, Kasun Karunanayaka, Mohammed Rabea Taleb Banalzwaa, Ibrahim Gamal Mahmoud Moteir, Adrian David Cheok

Imagineering Institute, Iskandar Puteri, Malaysia and City, University of London,UK
{kevin,ellyza,azhri,kasun,rabea,ibrahim,adrian}@imagineeringinstitute.org
http://imagineeringinstitute.org/

Abstract. In this paper, we discuss our work towards a new dining platform that uses magnetic levitating food and magnetic utensils in an initial prototype device. The ultimate goal of the project is a complete table with dynamic levitating food, but the current implementation is a set of levitating magnets that can be encased in food hovering over static locations. We investigated different weights and shapes of 3-D printed objects to mimic food and found that the levitating magnets are strong enough to support lightweight food. This magnetic levitating table can produce a playful and entertaining dining experience by moving and rotating to stay in place. The key novelties of this paper are the integration of food with a magnetic levitating table for playful interactions and novel dining experiences.

Keywords: magnetic levitation, magnetic food, levitating food

1 Introduction

Food is a basic human need, and the experience of eating food has been explored for maximum enjoyment. The variety of restaurants and methods for experiencing food are vast, yet new technology allows for novel and interactive ways to enjoy the basic activity of eating [11, 21, 19, 7]. Furthermore, new technology and studies have sought to create enhanced multisensory virtual environments for dining experiences [13, 8, 22].

One aspect of the dining experience that has recently received attention is the haptic experience of holding utensils, and how it may affect taste and overall experience. In one study, virtual chopsticks were used to enhance a virtual reality dining experience by providing force feedback when a user picked up food with chopsticks [13]. In another study, the effect of the texture of plateware was investigated, and the researchers found that food tasted rougher when eaten off of rougher plates [5]. Another study found that the freshness of pretzels differed between holding a crisp pretzel end or a soft pretzel end, regardless of the crispness of the tasted pretzel [2]. In another study, the weight of cutlery was suggested as a factor in perception of the taste of food, with heavier utensils resulting in a better experiences [18].

One concept that was previously proposed for novel dining experiences is the use of magnetic levitation [1, 20]. Magnetic fields can be used to levitate food, move food, modify the weight of utensils, add dynamic textures and create novel dining experiences. Magnetic levitation is commonly used in high-speed trains [14] and bearing-less motors [6, 9], but it has also been applied to other fields [12, 16]. Magnetic levitation has also been investigated as a novel haptic experience with researchers investigating methods to apply force to users on a magnetic inverted pendulum [4] and moving a levitating magnet using a haptic actuator [3].

In this paper, we describe our approach for magnetically levitating food to enhance dining experiences. We use a combination of permanent magnets and electromagnets to levitate a permanent magnet that can be encased within food. We investigate the feasibility of different shapes of food that can be levitated with this system, and find that shapes with larger moments of inertia and lower masses are suitable for levitation.

2 Prototype

Our approach uses permanent magnets to provide the levitation force and electromagnets to provide a centering force for the system, Fig. 1. This approach builds on previously described work for levitating a magnet [15]. The basics of the operation of our device use the unstable equilibrium at the center of a ring magnet to provide the force of levitation to a floating magnet. When moved off of the center of the ring magnet, the levitating magnet will be attracted to the ring magnet, so electromagnets are used to push the levitating magnet back to the center of the ring.

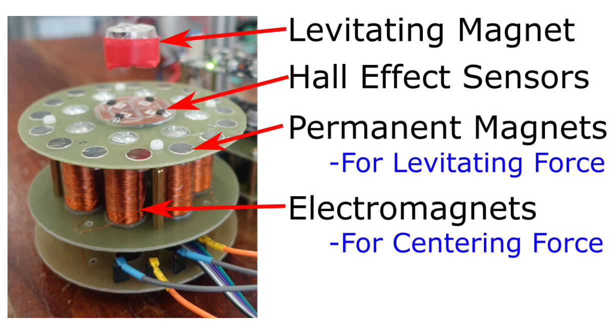


Fig. 1. Our system is composed of a ring of permanent magnets to provide levitating forces, a set of electromagnets to provide centering forces, Hall effect sensors for position sensing, and a levitating magnet.

Our system consists of a set of 16 cylindrical magnets with a diameter of 1 cm each in a ring with a total diameter of 9 cm at the centerline of the magnets. The cylindrical magnets produce a levitating force, and a set of 8 electromagnets provide a restoring force along the x- and y- axes, with two electromagnets on either side of the center of the structure in the x- and y- directions. The position of the magnet is sensed using a set of four Hall-effect sensors (Honeywell SS494B) located near the center of the structure. The Hall-effect sensors indicate the position of the levitating magnet and are used in a proportional-derivative (PD) control system implemented with an Arduino Pro-Mini, Fig. 2.

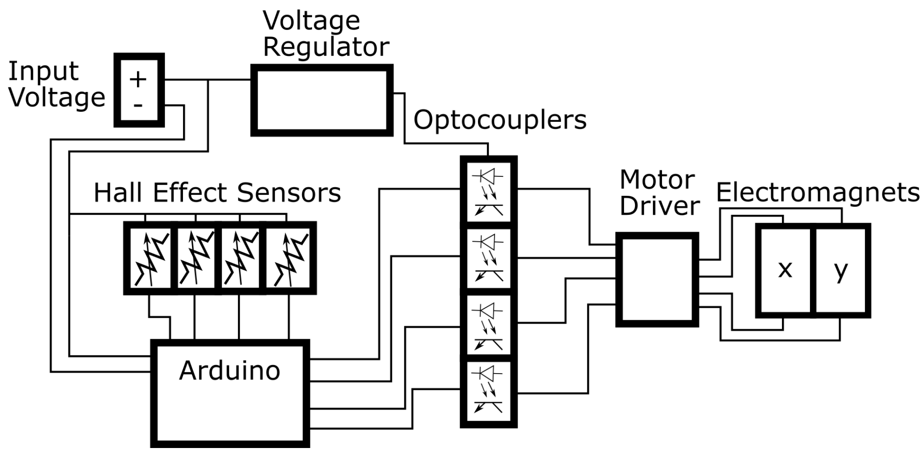


Fig. 2. Our system consists of Hall effect sensors for sensing the levitating magnet position, a PD controller implemented with an Arduino Pro-Mini, optocouplers, motor drivers, and electromagnets.

In our system, we used several different strengths and sizes of levitating magnets, but ultimately found that the most favorable magnet was a stack of two grade N52 magnets with one having a diameter of 2.5 cm and a height of 1 cm, and the additional magnet having a diameter of 2 cm with a height of 0.5 cm. Based on our modeling and experiments, the proper levitating magnet was determined based on the balance of the attractive force of the magnets forming the ring and the potential restoring forces of the electromagnets used to restore the magnet to the original position.

The dynamics of the system were determined using a combination of modeling and experimental verification. Modeling was done using FEMM 4.2 [17] in planar mode to determine the forces on the levitating magnet due to position and current in the electromagnet as well as the magnetic field ($|B|$), Fig. 3. The materials used in the model corresponded to the materials in the system, but the exact dimensions were determined using experimental verification. Verification was performed by determining the height at which a magnet levitated at the center of the ring with no electromagnetic input while is was constricted to motion in the vertical direction. In the model, a levitating magnet would require a total vertical force equal to its weight at that location. The size of the ring magnets were tuned to obtain a proper result. Similarly, the magnetic field could be used to tune the model electromagnets, with measured magnetic field corresponding to the simulated magnetic field at a particular current. The current to the electromagnets was changed from no current to maximum current while the magnetic field was read at the Hall-effect sensors. As the electromagnetic field from a solenoid is given by $\mathbf{H} = ni$ [10], where n is the turn density and i is the current, our results showed a linear correlation between the measured magnetic field and the current in the electromagnets. This was tuned in the model based on the number of turns simulated coils. Ultimately, after tuning the model system, it was used to determine a relationship between current in the coils, position of the levitating magnet, and the force on the levitating magnet. For sufficiently small motion of less than 5 mm, we found the equation of motion in a single axis to be $F = m\ddot{x} = 7.6x\left(t\right) + 0.012i\left(t\right)$ N, where $x\left(t\right)$ is the position in m, and $i\left(t\right)$ is the current represented by the pulse-width modulated (PWM) signal. Our model system was used to develop a control system using PD control. The PD controller had a relatively high derivative component with a lower proportional component. This model system was then used to understand how to make the levitating magnet more stable.

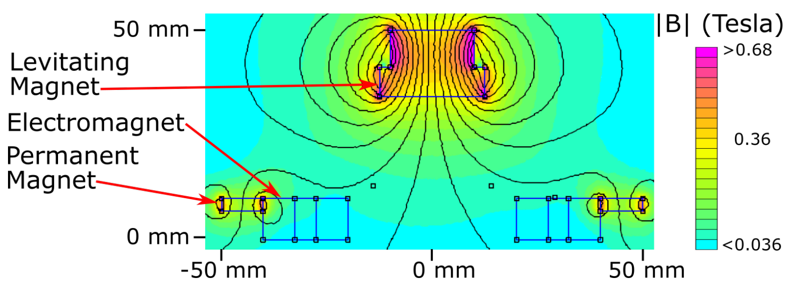


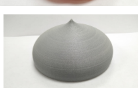
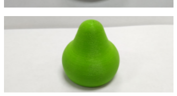
Fig. 3. The magnetic flux density, $|B|$, due to the levitating magnet, permanent magnets, and electromagnetic coils that have a current of half of the maximum current. The magnetic fields and forces of the permanent and electromagnets were modeled using FEMM 4.2. The current in the electromagnetic coils was varied per an experimentally-derived relationship between the supplied PWM control signal and the resulting magnetic field.

After successfully testing the system to levitate magnets, different shapes of magnetic foods were tested on the system. In order to determine the effects of added masses to the magnetic foods, we used 3-D-printed shapes. The 3-D-printed shapes had changes in the total mass, size, and distribution of mass. Furthermore, the shapes were intended to mimic shapes of common foods, including pears, pumpkins, onions, and pizzas.

3 Effects of Objects on Levitation

We tested multiple different 3-D printed objects with changes to the size, mass, and mass distributions. We found that the center of mass needs to be at the same center of mass of the levitating magnet, otherwise the object would not levitate. Furthermore, we found that, except for lightweight and heavy objects, high moments of inertia were favorable to low moments of inertia for stable levitation, Table 1. The table is best suited for levitating lightweight, disk-shaped objects with a height approximately equal to the height of the levitating magnets, which is about 25 mm.

Table 1. Success of levitating different shapes

Shape	Maximum Diameter (cm)	Mass (g)	Moment of Inertia (g·cm^2)	Stability
	10.5	40	233	Stable
	5.0	23	55	Unstable
	7.0	25	102	Unstable
	10	75	511	Unstable
	12	34	226	Stable
	4.5	12	22	Unstable
	3.5	5	6.8	Stable

This work showed that in the current system, several common shapes of food could be stably levitated for interactive displays and even to be removed from the magnet and eaten. This could provide an attractive display to entice customers to order food or be used as a unique dining experience where floating food is directly consumed and brought out on a levitating plate.

4 Applications to Levitating Food

Our results show that stable levitation of food is possible and can provide a novel dining experience. It can also be used to entice customers to enter a store as an attractive display. People interacting with the levitating magnets often take photos and play with the levitating table. When used as an element in dining, it can provide a unique and playful dining experience.

Our system currently consists of three of these tables arranged to levitate three magnets holding food, Fig. 4. This system is interactive, but users must remove the magnet from the food before eating. This can be done either by disposing of the magnet, or carefully removing the food from the levitating magnet without disturbing the magnet away from the controllable region of the table. The system is likely best used as a display in its current form, but it can also be an interactive way to dine or present a dish to a customer.

a) b)

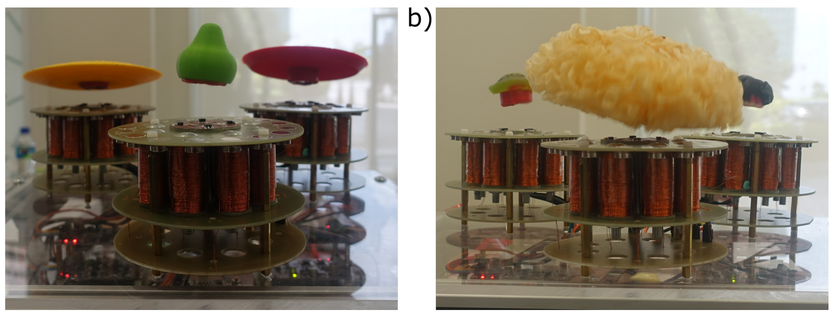


Fig. 4. Our current system consists of three tables positioned to levitate magnets holding food. a) Food is represented with different 3-D printed objects, and b) real food is tested and can levitate.

5 Future Work

Our current device has some limitations that will be overcome in future work. Currently, the height of the levitating magnet is determined by the ring of permanent magnets in the system. This cannot be changed dynamically, except by adding weight to make the height lower. Furthermore, the system is confined to a single levitating location. We did some investigation into if we could move the magnet, but found that the system works best if the levitating magnet remains at the center of the ring magnet, and becomes less stable when moved away from center. We plan to extend our work in the future to use only electromagnets so that the levitating magnet can be fully manipulated for height movement as well as movement in the plane. This work will enable a fully novel dining experience with food moving around the table automatically without being manipulated by hand.

In addition to extending the magnetic table for full motion of levitating magnets, we will also investigate novel methods of interacting with the magnetic dining table. These methods will include levitating food, moving food, modifying the weight of the utensils, and adding dynamic textures to a meal. We expect that these novel interactions will enhance dining experiences to create new methods for interacting during meals.

6 Conclusions

In this paper, we have discussed our simulation, development, and technical results on a novel platform for a magnetic dining table. The current system consists of a set of permanent magnet rings that provide levitation force combined with electromagnets that provide a centering force. We investigated the use of different shapes of food that can be levitated with the current system and found that shapes with larger moments of inertia were more likely to be stable. The system can be currently implemented for unique dining experiences with lightweight food that has been shaped with an opening for the levitating magnet. The key novelties of this paper are the integration of food with a magnetic levitating table for playful interactions and novel dining experiences.

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