The Hover Table: A Responsive Table for the Future

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1. Overview

Why have a side-table and a coffee table when all you care about is the different heights? Why not have a table that can adjust to different needs? Tables have not changed much since their conception as a functional component in homes and workspaces. However, we were inspired by the film series “Back to the Future”, in which by the year 2015, hoverboards were a popular mode of transport. While making a hoverboard may not be practical, a hover table can solve key issues with the static design of tables today.

We decided to implement this primarily as an electromagnetic system in order to maximize the “cool factor” and encourage broader thought for design of the future. Furthermore, if the base of the system were built into the floors of homes, there would be no more stubbed toes at night!

Our design has two stages of improvements over normal tables. First, the hover table can be adjusted to different heights with a simple electronic input. Hence, if an object is placed on top of the table, it will automatically adjust the electromagnet strength to maintain its position at the desired height. In the second stage, we also hope to add tilt rectification, so that if an object is placed closer to an edge of the table, thus causing the surface to tilt, it will recognize the tilt and adjust the balance of the tabletop correspondingly.

2. Design

2.1 Terms

There are some key terms to keep track of in this proposal:

ADC: an analog to digital signal converter
DAC: a digital to analog signal converter
Darlington: a current amplifier circuit
2-axis accelerometer: a sensor which can determine if it is tilted in any direction in the xy-plane
IR (Distance) Sensor: a sensor which uses the reflection of infrared light it emits against a surface to determine distance to that surface
Base: The part of the table that rests on the ground with the magnets and sensors.
Tabletop: The bismuth ring and flat surface which should hover above the center of the base.

2.2 Project Overview

Figure 1 below summarizes the important blocks of our project:

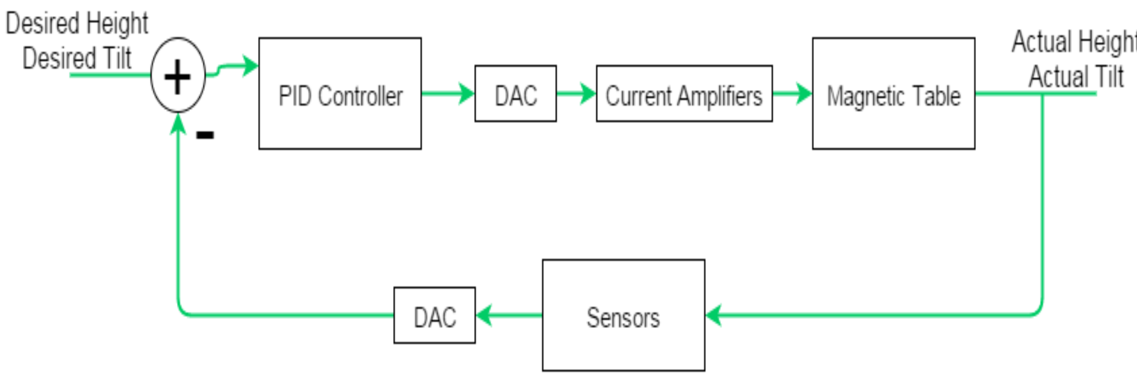

Figure 1: Overall Schematic

In short, we get current height or tilt (bottom loop) and the desired one (top input), and feed that into the PID Controller, which uses proportional, integral, and derivative components to determine what changes should be made for the table. Then, the digital-analog converter sends an analog signal to the current amplifiers, each of which send their new current to their corresponding electromagnet to cause a change in the table's position.

2.3 Decisions and Motivation

The driving factor behind this project is implementing a control system for a table in order to make it more responsive to daily life. To truly achieve completion of a marketable hover table, we could implement both the height and tilt controls, though just accomplishing even the first of those would be a functional and flexible object.

We decided to use electromagnets because they would allow a floating surface and fast control with pulse width modulation, which cannot be done with permanent magnets. This pairs nicely with the bismuth tabletop, since bismuth naturally produces an opposite magnetic field for any field applied to it, thus making it a strong candidate for levitation projects.

In the case where the magnetic table becomes infeasible, the electromagnetics will be replaced by servos, which use pulse width modulation voltage waves as well to set a certain angle (theta). The servos would undergo a similar test as the electromagnetics where heights will be mapped to certain outputs of the controller instead of the current amplifiers.

3. Implementation

3.1 Magnetic Table (Plant)

There will be four electromagnets, each 90 degrees away from its neighbors, at the base of the table, which should be a circle approximately 9 inches in diameter. (Fig. 2) The tabletop will consist of a bismuth ring of approximately 6 inches in diameter, covered by a non-conductive, non-magnetic surface such as laser-cut wood on top to hold items. (Fig. 3) To control each magnet, one sends pulse-width modulated (PWM) signals to each magnet. To keep the surface level, one sends the same signals to each magnet—one can increase pulse widths individually to fix tilt, or altogether to raise or lower the tabletop. The overall appearance would be a somewhat less polished version of Figure 4.

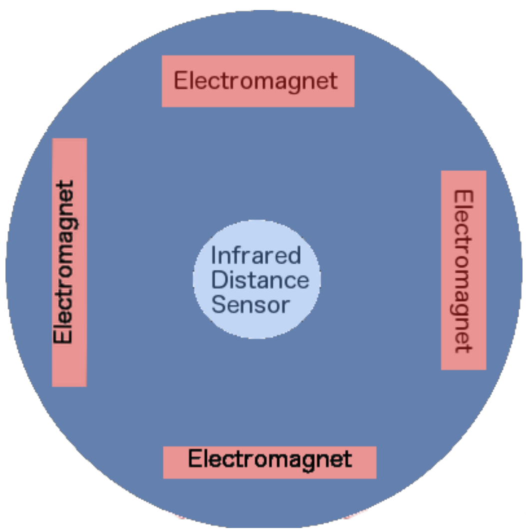

Figure 2: Table base

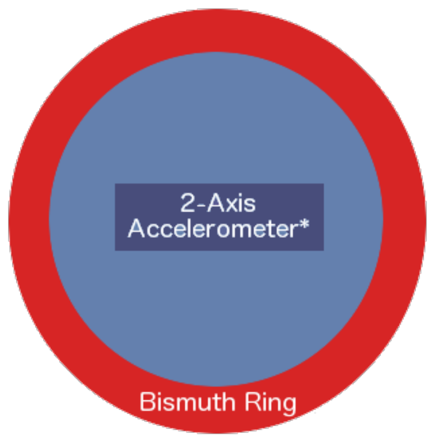

Figure 3: Tabletop

Figure 4: Finished table setup.

3.2 Analog to Digital Converter

This will take the analog signals from the sensors and digitize them such that the FPGA will be able to process them. There is one for each sensor, yielding two in total.

3.3 Sensors

There are two key sensors for this project. The first is the IR sensor, which will be placed at the center of the base and will consistently take measurements of how high the tabletop is relative to the base. This is sent to the controller to adjust the electromagnets as needed. The second is the 2-axis accelerometer, which, if we reach that stage, will send a stream of data about the current tilt of the tabletop, which will be sent to an expanded version of the controller, which will adjust individual electromagnets to balance the tabletop.

3.4 Controller

The PID Controller is responsible for setting the different current levels in response to the sensor reading of the table. The inputs are 3 types of errors; the height error, theta x error, and theta y error. The height error is the difference between the desired height and the actual height of the table. Theta x and theta y errors represent the tilt of the table where the error lies in the difference between the reference angles minus the actual angles read by the accelerometer sensor. The desired height can be set by switches 3 through 0 on the FPGA where 10 cm is the maximum and 0 the minimum. Since the table needs to be flat to function, both reference angles for theta x and theta y are zero.

Figure 2 below shows an in depth look inside the controller. All 3 input errors will be processed by a corresponding proportional gain K_p, an integral gain K_i, and a derivative gain K_d. The proportional gain will improve performance by reducing the time constant of our system, thus causing a higher reaction speed to sensor inputs and making the table respond more quickly to changes. The implementation of K_p is merely making a parameter to multiply against the error. The integral gain is created by simulating a sum of a certain number of past error values and multiplying them by K_i. This will reduce any steady-state error, giving the table precision in order to keep tilt a minimum. K_d will be multiplied by the derivative of the error, which consist of looking at the difference between the current error and the error in the previous clock cycle. The derivative gain will provide stability so that the table won't overshoot its height or wobble recklessly when trying to keep it flat.

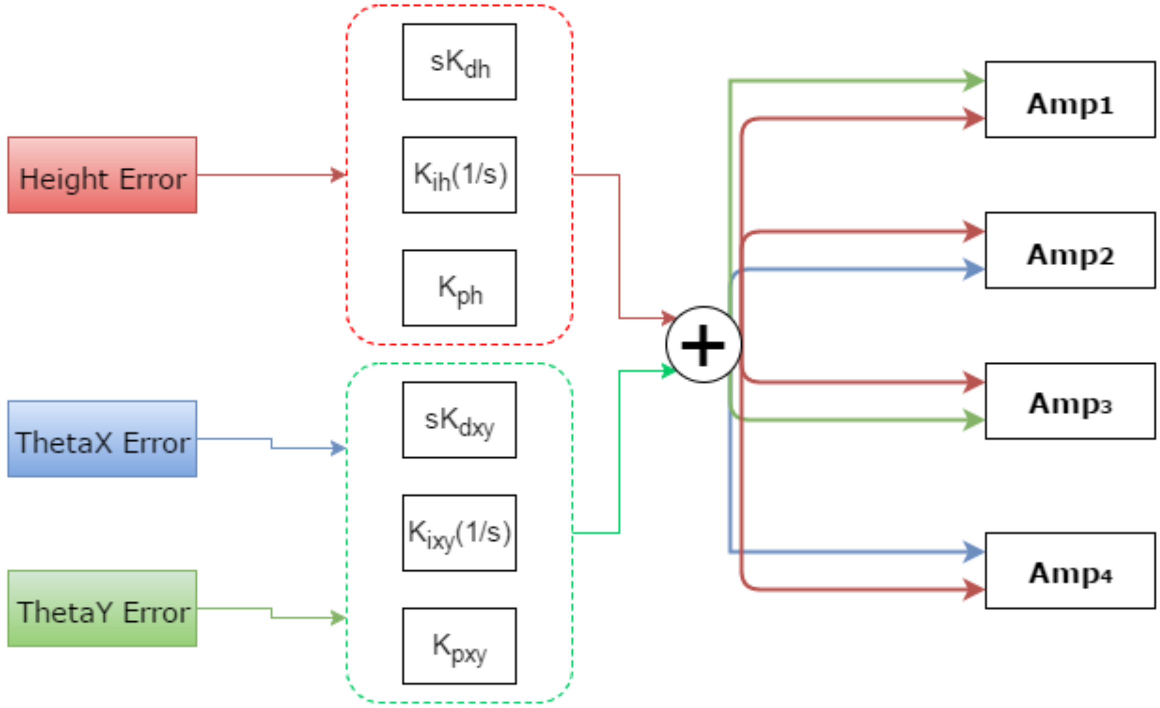

Figure 2: PID Controller

Once each error has been processed, they are summed together and outputted as a digital voltage signal to 4 different amplifiers, each one corresponding to a magnet on the base plate. The processed value of the height error goes to all 4 amplifiers, but the processed value of theta x and theta y error only effects the amplifiers along the corresponding axis.

3.5 Digital to Analog Converter

The digital to analog converter (DAC) receives a digital voltage signal from the controller and produces an analog voltage signal for the current amplifiers. There are 4 DACs in total; each in-between the controller output and amplifiers input. These will take the output from the FPGA and create an analog signal for current to send to the electromagnets.

3.6 Current Amplifiers

The current amplifiers take 4 different analog voltage signals from the DAC and provide the current for the electromagnets attached to the base. Each amplifier is a Darlington circuit, which consists of an emitter-follower transistor driving a common-emitter transistor. A schematic can be seen below in figure 3.

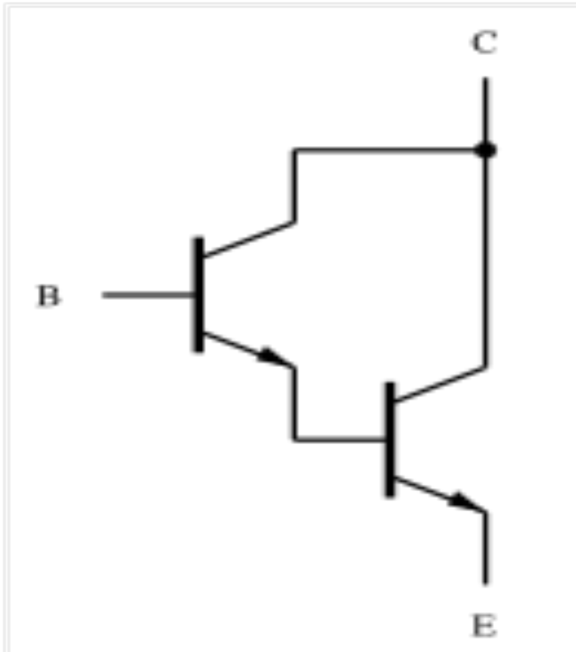

Figure 3: Darlington circuit schematic

The Darlington configuration is well known for a having a high current gain, allowing input analog voltage signal to small in amplitude, but still provide precision current to the electromagnets.

4. Testing

4.1 DAC/ADC

The DAC and the ADC will be tested by providing a series of simple signals through each of them to confirm functionality. The series will include a flat signal, a low frequency signal, a high frequency signal, and a buffer signal where the signal will enter the DAC, then be processed by the ADC, and result in being the same signal.

4.2 Sensors

For the distance beam sensor, an object will be placed 1cm, 5cm, and 10cm away from it in order to record the analog values they produce. If the sensor is suspected of being buggy, the same test can be run again, and the values can be compared. A similar test will be done for the accelerometer using angles instead of distance.

4.3 Magnetic Table

For each distinct amount of current applied to the electromagnets, the height of the table will be measured. This measurements will be used by the controller to decide the current the amplifiers use. If an electromagnet is suspected of being buggy, the same test can be run again and the height values compared.

4.4 Current Amplifiers

The current amplifier will be built and simulated on LT Spice; a circuit schematic builder that allows for testing of the circuit before it is built. Once the circuit's gain is properly set in SPICE, the circuit's input will be provided different voltage signals by the function generator and the output will be measured by the oscilloscope to ensure a correct current signal is produced.

4.5 PID Controller

The PID Controller will be given different simulated sensor readings to correspond to different states of the table in order to make sure proper values are being sent out to the amplifiers. The different states to be tested are table too low, table to high, table tilt on x axis, table tilt on y axis, and table tilt on all axis.

5. Timeline

	11/2 – 11/8	11/9 – 11/15	11/16 – 11/22	11/23- 11/29	11/30 – 12/6
Order Electromagnets, BJTs, and sensors.	■				
Build Spice of Current Amplifier	■				
Test Amplifier		■			
Build Magnetic base and table		■			
Test Sensors and electromagnets		■	■		
Build Controller			■	■	
Test Controller				■	
Debug System				■	■

6. Conclusion

The hover table will bring furniture into the future, and make those who watched Back to the Future II when it first came out proud. Furthermore, it will have a range of applications, from simply making furniture adjust for different purposes, to increasing accessibility by creating a more responsive table.

In addition, it will be an exciting project for us, as neither of us have extensive experience with magnets, but it is all the more exciting to try given the resources we have now. Plus, our combined skill sets cover a broad range of all the other parts that are involved in this project, including controls and circuitry. This venture will definitely be an exciting learning experience with visually pleasing results to show for it.

7. Appendix

Part Name	Number Required	Price ($)
Grove Electromagnet	4	13.50
Bismuth	-	20
2-axis accelerometer	1	-
IR sensor	1	-