Three-Dimensional Electronic Hand-Tracking System
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Original Abstract
We propose to create an electronic hand-tracking system to be used for manipulating virtual objects. The machine will work off of principles found in a theremin, specifically the theremin’s ability to alter its output depending on the position of the user’s hand. By connecting a microcontroller to the antenna, it will be possible to take measurements and analyze them in real time on a computer.

Theremin:
The theremin is a musical instrument in which the musician changes the pitch by moving their hand closer and further from the instrument’s antenna. Basic theremins have a circuit that consists of one fixed oscillator and another variable oscillator. The variable oscillator has a frequency that varies as one moves their hand closer to the antenna of the oscillator. The antenna acts as one plate of a capacitor and the operator’s hand is the ground plate. By changing the distance of one’s hand to the antenna, the capacitance of the oscillator’s antenna varies and therefore varies the output frequency. The constant oscillator circuit is necessary in order to beat the signal from the varying oscillator. “Beating”, means roughly to combine two similar frequencies to observe a much lower frequency equal to the difference of the combined frequencies. By beating the frequencies, we can use extremely high frequencies for the varying circuit to achieve high sensitivity and still have a measurable output.

We can easily use this system to measure the distance of a grounded object. Instead of directing the output to speakers, we can use a program to determine distance from frequency. With three theremin units, we can triangulate the position of a grounded object (such as a hand) within the region of the three antennae.

Old Design:
Our first theremin circuit design consisted of NAND gate oscillators. A NAND, or NOT AND, produces a signal every time the A input differs from the B input. A NAND gate oscillator consists of a NAND gate, a resistor, and a capacitor. Our variable oscillator also had an antenna in parallel to the capacitor, this way the capacitance of the circuit would change as one approached the antenna. The capacitors for the oscillators had very low values (around 5 picofarads). This was to increase sensitivity since a person’s hand and an antenna would produce approximately a picofarad of capacitance.
This design produced many problems for our team. Using oscilloscopes, we examined the signal from the outputs of both oscillatory circuits and the beat signal. The first problem was that the circuit was extremely nonresponsive. The signal from the variable oscillator only showed a noticeable change in frequency when the hand was placed directly on the antenna. Secondly, when the variable oscillator showed a change in frequency, the isolated constant oscillator also varied with an equal change in frequency resulting in no change in the beat signal. After many weeks of trying to diagnose the problem, it was concluded that the extremely low capacitor values resulted in the solderless breadboard having a large contribution to the overall capacitance of the circuit. When a hand came close to the antenna, it also came closer to the breadboard, which changed both the capacitance of the variable oscillator and constant oscillator. This was confirmed when we tested the circuit with the antenna far from the breadboard. No change in frequency in the constant oscillator was observed. This design was still scrapped due to the large amount of noise and insensitivity.

**New Design:**

The redesigned circuit is based around 555 timer integrated circuits operating in astable mode to generate the signal. One timer circuit is constructed to produce a constant frequency while a second has the frequency change as the capacitance of an antenna changes. The two frequencies are beat together and the beat signal is passed through a low pass filter in order to generate a cleaner signal that is then passed to the Arduino micro-controller.

This circuit has been tested with an oscilloscope and is working well so far. By adjusting the variable resistor on the constant oscillator, we can manually calibrate the circuit to produce a beat signal of zero frequency when no hand is present. The sensitivity of the circuit is much better than the last circuit, recognizing our hand from a few inches, however we plan to increase the sensitivity by adjusting the passive components. In the future, we plan to use three of these devices to triangulate a position of the hand.
Program:

The frequency readings from each of the three antennas are then passed to a Python script. This script has two parts: a calibration phase and a continuously looping phase that runs a real-time graph of the objects position in 3d space.

The goal of the calibration phase is to find the calibration constant for each antenna that is needed to convert the circuit’s frequency to the object’s distance from the antenna. Since there is a linear relationship between the frequency and objects distance, it is possible to calculate this constant by comparing the frequencies at two different positions with the following relationship:

$$K_{\text{calibration}} = \frac{\Delta \text{position}}{\Delta \text{frequency}}$$

Once the calibration constant is found, it can be multiplied by the circuit’s frequency to calculate the object’s distance from a reference point. This process is performed for each antenna to account for possible variance between the antennas and circuits. When the calibration process is complete the script will enter the graphing phase.

The graphing phase calculates the position of the object and plots the position on a 3d graph. The script will read the Arduino’s three frequency outputs and convert them to distance by multiplying the readings by their respective calibration constants. The script will then create a 3d graph using the three distances as the current coordinates of the object relative to a specific center point.

For the Future:

Our first plan of action is to increase the sensitivity of the theremin hand tracking circuit. Experimenting with lower capacitance values and better antennae can accomplish this. The best antenna would be a conducting sheet, as would be observed in a plate capacitor. We can experiment with this design first to see what our maximum sensitivity could be, then work to make a sleeker antenna design with similar sensitivity.

It is also uncertain how three antennae would interact with each other. In order to avoid interference between each of the three antennae, the antennae could each be turned on and off in sequence. While an antenna is on, the distance of the object from the antenna would be calculated and it would be shut off as soon as that is completed. Each of the three distances computed would then be used to get individual coordinates of the object’s position. A program running on the Arduino board would control the turning on and off of the antennae.
Expenses:

We have spent approximately $200. The cost of the project went mostly to passive components for both circuit designs and the solderless breadboard. We also purchased probes and tools used with the oscilloscope. We plan to spend much more on our final design in order to make the circuit self-calibrating and reliable.

*All circuit diagrams were made using www.circuitlab.com*