Squishy Circuits as Interface and as Teaching Tool

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ABSTRACT
Squishy Circuits is a new approach to exploring and learning electronics. This method uses two homemade sculpting dough recipes- one that is conductive, and another that is insulating. Squishy Circuits can be used to model basic circuits, but can also be used as an interface for more advanced projects, which will be discussed in this paper. We also present our results of using Squishy Circuits as an educational tool. Finally we present our research of the dough's electrical resistivity, which is important to know when using the dough as a tangible input mechanism.

Author Keywords
Squishy circuits, conductive play dough

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI):Miscellaneous.

General Terms
Design, Experimentation

INTRODUCTION
Traditionally, students are introduced to electronics using prototyping boards or soldering irons. The Squishy Circuits project attempts to change the way students, particularly very young students, are taught by using simple components, such as LEDs, motors, and buzzers, and combining them with homemade sculpting dough [13]. This allows students to sculpt circuits in a playful, non-permanent, activity.

This work is based on the large body of literature pertaining to sewn and painted circuits [2]. We noticed, however, a lack of sculptable electronics, which we felt would be easiest for very young children (preschool, kindergarten, and early elementary school aged) to work with. This realization led to the idea of using play dough to create circuits. The use of play dough to teach electronics is not a new concept. Physics teachers have used Play-Doh® brand molding dough to conduct labs in both electricity and resistance [6, 10, 11]. To the best of our knowledge, though, play dough has not been pursued further as an electronics teaching tool. We sought to provide a non-toxic recipe for dough which utilized only commonly available ingredients and was conductive enough to facilitate circuit design. We also wanted to develop an insulating dough so that more advanced circuits could be created without relying simply on separation to prevent short circuits.

Various dough recipes were developed and tested and Squishy Circuits was born. We established two different recipes, one salt based for the conductive dough and one sugar based for the insulating dough [13]. Moving forward, we began using Squishy Circuits as an educational tool and have created more advanced projects that utilize the dough's unique, hand-on approach to electronics.

SQUISHY CIRCUITS AS A TEACHING TOOL
Motivation and engagement in science has a high correlation with several factors including lessons that are hands-on and activities that allow individuals to approach the project in their own ways [3, 8, 9, 12]. Squishy Circuits, as a tangible circuit creation technique, provides a medium for allowing such exploration.

Research has shown that the confidence levels in an individual's skills are proven to be increased when positive stimuli are given for success, especially when they are required to think critically[8, 12]. This is why lighting an LED is often the first challenge we present to students. Students must think of how electricity behaves and create a circuit. Success is immediately evident with the LED, or motor, turning on.

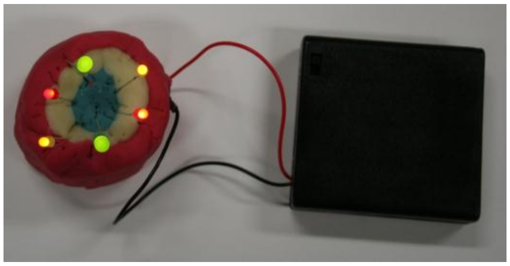

Figure 1. A simple circuit created using a 6V battery pack, conductive and insulating dough, and LEDs.

TEI 2012, Feb 19-22, 2012, Kingston, Ontario, Canada.

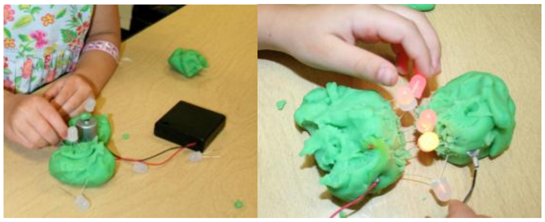

Figure 2. Circuits created by pre-school (aged 3-5 years) children.

Our experiences with Squishy Circuits in the classroom seem to validate these ideas. We have used Squishy Circuits with many age groups, from age 3 to adults, and have found most circuit sculptors are engaged in the activity and successfully learn conceptual electronics, such as short circuits and circuit continuity.

Figure 2 shows students in a preschool classroom (ages 4-5) sculpting circuits. The students were each given a set of Squishy Circuit components, and walked through the creation of a simple LED circuit [4, 5]. They were then given a chance to play with motors, buzzers, and unlimited LEDs to create their own designs. Every child was successful in creating a circuit with, at most, a few minutes of individual attention. The activity was then run with a class of 3-4 year olds with equal success. It should be noted, however, that the younger class preferred motors to LEDs. It is unclear to us whether this was due to the bidirectionality of motors (as opposed to LEDs) or due to their love of spinning things.

We are encouraged by what we have seen and are will be doing more research on the effectiveness of Squishy Circuits as a teaching tool in early childhood (pre-school and kindergarten) in the future.

SQUISHY INTERFACES

While our primary focus in developing Squishy Circuits was originally to develop a teaching/exploration tool for young children, we began to see that the conductive dough could also be used as an interface for microprocessor driven projects. This can be accomplished by using the conductive dough as an input based on its resistance, which changes with the dough's geometry (as discussed later in this paper). Code and instructions for reproducing the projects in this section can be found on the Squishy Circuits website [13].

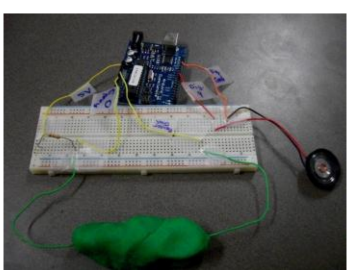

Figure 3. A sound-producing circuit which uses conductive dough to control pitch.

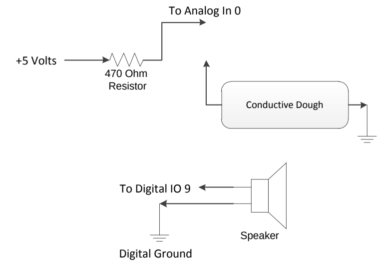

Figure 4. Schematic for the Squishy Sound circuit.

Squishy Sound

For this project, Squishy Sound (shown in Figure 3), we have used an Arduino UNO board [1] and created a voltage divider between a known resistor and the conductive dough (Figure 4). The microprocessor reads the voltage of the conductive dough via an analog input, and converts that value into a tone frequency. This frequency is emitted through an external buzzer or speaker. When the user manipulates the dough, by stretching or squeezing it, the buzzer changes frequencies in real time. The pitch is higher if the resistance is higher and lower if the resistance is lowered.

Squishy Red-Green-Blue (RGB) Controller

Another project that can be done with Squishy Circuits and a microprocessor is the Squishy RGB LED Controller, shown in Figures 5 and 6. In the same manner as Squishy Sound, three separate pieces of conductive dough can be utilized as input devices which control the brightness of a cluster of three different LEDs, one each of red, green, and blue. In essence, this creates a large pixel which mixes the three lights into different colors based on their individual intensities. For example, if the dough inputs are manipulated to have a low resistance, all three LEDs will be brightly lit and create a white light. However, if the resistance of the dough for the green LED is increased, the red and blue LEDs will be more brightly lit and the resulting color takes on a purple hue. This project works best in combination with a semi-translucent diffuser to help mix the colors.

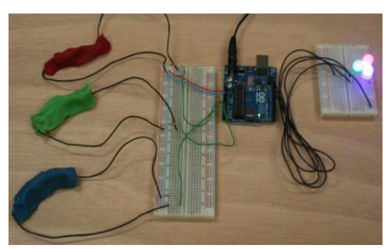

Figure 5. A squishy interface for RGB LEDs.

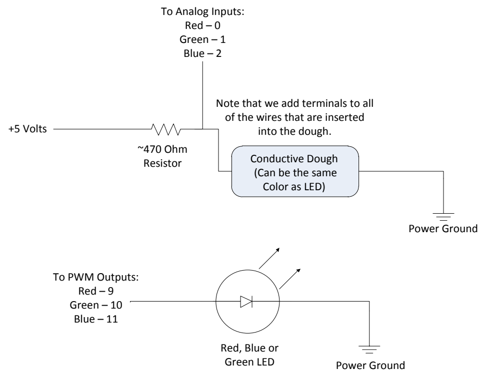

Figure 6. Schematic for the Squishy RGB Controller circuit.

RESISTIVITY TESTING

The use of the Squishy Circuit dough in tangible interfaces is dependent on being able to reliably characterize their behavior. The easiest way to use conductive dough as a transducer is to take advantage of the fact that resistance is related to geometry:

$$Resistance(\Omega) = \frac{Resistivity\ (\rho) \cdot Length(l)}{Area(A)}$$

,where resistivity is a property of the material. If resistivity is stable over time and from batch to batch, manipulation of the dough's shape will change its resistance in known ways. Below, we describe our results in characterizing the resistivity of these doughs.

Resistivity Testing of Conductive Dough

Four independent batches of dough were made following the published recipe [10]. While the recipe does not specify the exact quantity of flour needed, to reduce variability 0.25 cup of flour was used for each batch. Samples of the dough were then inserted into the testing apparatus, a 0.5 inch PVC tube. Through the tube, four tin-copper wire electrodes were inserted, with the centermost electrodes placed one inch apart. A current source was attached to the outer two electrodes, while a voltmeter was attached to the centermost electrodes. This setup is shown in Figure 7.

Using this four-wire measurement technique, or Kelvin measurement, all effects due to wire resistance and

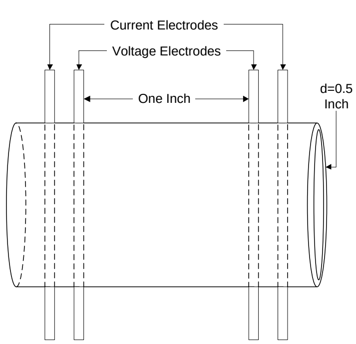

Figure 7. Test fixture used for resistivity testing of conductive dough.

electrochemical reactions are negated [4], resulting in the resistance of the conductive dough sample, measured in ohms. It should be noted that because of these electrochemical effects conductive dough does not behave like an ideal resistor and current measured in the circuits above will be significantly lower than one would predict from Ohm's law.

The test was automated using LabVIEW [7] measuring voltage at currents from 1 to 50 mA in 1mA steps. Transient effects were filtered by waiting 750 ms after each step in current before making a measurement. The resulting data had a strong linear correlation (r^2=99.8-100%), indicating a resistivity independent of current. The data presented in this paper represents the resistivity of the dough at 50mA.

Fifteen samples of the first batch were measured to determine stability of resistivity readings within a batch. Then 5 samples of each of the remaining batches were measured. The results of our tests on multiple samples of multiple batches are shown in Table 1. The uncertainties given are ± 2 standard deviations of the mean.

Batch	Number of Trials	Resistivity Ω-inches
1	15	10.33±0.08
2	5	9.96±0.12
3	5	9.04±0.13
4	5	10.03±0.09
Average		9.8±1.1

Table 1. Resistivity results for the conductive dough.

Samples within a single batch vary in resistivity by less than 2%. While batch to batch variability is greater than intra-batch variability, we still find a reproducibility of approximately 11%.

Resistivity Testing of Insulating Dough

A similar process was used for measuring the resistivity of insulating dough. The published recipe was standardized to use 38mL of vegetable oil, 55mL of deionized water, and an additional 5 tablespoons of flour. Since the resistivity of the insulating dough is much higher than that of the conducting dough, the geometry and current source for the experiment were changed. A 0.225 inch diameter PVC pipe was used in place of the 0.5 inch PVC pipe, and the voltage was measured across 0.125 inches. Furthermore, a 0-120V AC 60Hz autotransformer was used to provide power instead of a bench DC power supply. Ten randomly selected data points, spread throughout the 120 volt range, were collected and linear regression analysis was applied to the data set. All of the produced equations also had high correlation (r^2=99.9-100%). Using the regression equations the resistivity at .5mA could be calculated via Ohms law and resistivity equations, as done with the conductive dough.

Batch	Number of Trials	Resistivity kΩ-inches
1	15	34.20±0.77
2	5	34.69±0.36
3	5	32.21±0.90
4	5	30.2±1.1
Average		32.8±4.2

Table 2. Resistivity results for the insulating dough.

Note that these measurements are in kΩ-inches rather than Ω-inches as above. Although variability is greater than with the conductive doughs, we still see an intra-batch variability of approximately 2% and a reproducibility of better than 13%.

Resistivity Testing of Commercial Play-Doh®

While these results show that the conductive and non-conductive doughs have reproducible resistivity, it is interesting to compare their performance to proprietary Play-Doh®. We found considerable variation in resistivity with color, as shown in Table 3.

Color	Number of Trials	Resistivity Ω-inches
Green	3	12.412±1.644
Orange	3	16.14±3.039
Red	3	16.83±1.843
White	3	14.702±2.99
Black	3	12.756±3.673
Average		14.568±2.447

Table 3. Resistivity results for commercial Play-Doh®.

Because of the small sample size, the resistivity range shown is a 95% confidence interval based upon the t-distribution. The resistivity of the commercial dough is similar to that of the conductive homemade recipe above. Thus the commercial dough seems suitable for Squishy Circuit applications. However, the cost of buying the commercial dough is typically substantially higher than the cost of making the homemade dough. Additionally, from an education perspective, using the homemade dough means that all ingredients, and their quantity, is known, which makes discussions about the science behind the project easier to facilitate.

CONCLUSION

We have presented how Squishy Circuits can be used both to teach electronics, even to young children, as well as to interface with microprocessors. Given the low cost and consistent resistivity of the dough, it appears to be a viable input mechanism for microprocessor projects. Ongoing and future work includes development and assessment of curricula using the Squishy Circuits, as well as further explorations of squishy interfaces.

ACKNOWLEDGMENTS

Removed in draft for confidentiality.

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