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Kinetic Mousepad

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Piezoelectric Mouse Pad

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Abstract
In today's digital world, people spend much of their time in front of a computer. While there have been many attempts to harness energy from this group of people, one area that has seemingly never been tapped into is the movement of a mouse, an essential component of using a computer. This paper explains our process for harnessing this untapped energy source. By utilizing force exerted on Piezoelectric transducers from the movement of a mouse over the transducers, we are able to generate current via the force of the hand and the mouse on the mouse pad. Initially, we found that the force directed specifically onto the transducer was not concentrated enough to generate substantial current. To better localize the overall force on the transducers, we utilized magnets within the mouse and below the transducers. When the mouse passes over the transducer, the magnets attract, which pulls the magnet into the transducer. With an array of these transducers set up, much of the movement of the mouse is able to be harnessed and used as needed.

Introduction

In today's digital world, people spend much of their time in front of a computer. While there have been many attempts to harness energy from this group of people [1]-[8], one area that has seemingly never been tapped into is the movement of a mouse; an essential component of using a computer. Piezoelectric transducers are one element that can be incorporated into our everyday lives to take advantage of wasted energy. The use of piezoelectric transducers to generate electricity has an estimated compound annual growth rate of 7.4% (2021-2026) [9]. We hope that through our paper and our prototype we can further contribute to this growing source of green energy.

On a basic level, piezoelectric transducers work by taking in applied mechanical stress, which shifts the positively and negatively charged atoms of a piezoelectric crystal out of equilibrium. This polarizes each side of the crystal and its charge is then directed by copper wires to generate current [10]. Pavegen, a UK-based company creating piezoelectric tiles [11], is one example of a successful business involved in producing this type of green electrical energy. Pavegen has more than 200 sites around the world that vary from powering Kia motor factories in Korea to public infrastructure projects in Rio De Janeiro [12]. From Pavegen's success, we believe that the use of piezoelectric transducers has great potential. Therefore, we were interested in incorporating the energy-producing capabilities of piezoelectric transducers into our own project.

Methods and Approach

To determine the most effective and practical approach to generate electricity from the movement of a mouse, the engineering design process was implemented. Before brainstorming possible solutions, it was first decided that the method of electricity generation could not be contained solely within the mouse. This is due to the increased complexity of the additional mechanisms that would be needed to transfer electricity from the mouse to outside applications and the need for the mouse to be as light and usable as a standard mouse as possible. Therefore, the concept of a mouse pad that creates electricity when a mouse moves over it was chosen, and ideas for how to generate electricity from the movement of a mouse over a mouse pad were brainstormed. Brainstorming resulted in the generation of three possible methods of electricity generation. The first concept was based around Faraday's Law and the passing of a magnet through a coil to generate electricity. Faraday's law states that when a magnet is moved through a loop or coil of wire, an electric current is generated. To take advantage of this phenomenon, we proposed creating a mouse that contained a magnet that would attract another magnet embedded within the mouse pad. In turn, the magnet in the mouse pad would move on a track passing through a copper coil to generate electricity (Fig 1). This idea was quickly discarded after additional research was done, as it was determined that magnets only produce an electric current when passing through a copper coil parallel to the coil's axis [13], not perpendicular as was proposed. This would force an inconvenient setup to be created, requiring the magnet in the mouse to repel the magnet along the copper coil axis and making the whole system more unreliable.

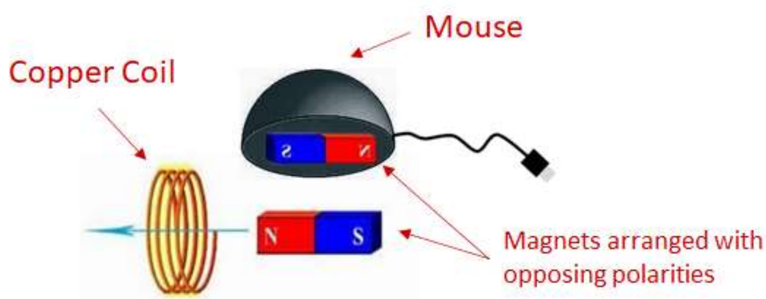

Fig 1: Initial 2D Model (Concept 1)

The second concept utilized piezoelectric transducers (also known as elements or generators), which turn mechanical energy into electrical energy. To accomplish the conversion of mechanical energy to electrical energy, piezoelectric transducers contain certain piezoelectric crystals, such as quartz (SO_2) whose lattice structure is made up of positively charged silicon atoms and negatively charged oxygen atoms. Under standard conditions with no mechanical stress being applied to the crystal, these positive and negatively charged atoms balance each other out and make the crystal electrically neutral. However, when mechanical stress is applied, squeezing the crystal, the center of the positive charge shifts slightly in one direction, and the center of the negative charge shifts slightly in the opposite direction. This is the piezoelectric effect. One side of the crystal becomes more positively charged and the other side becomes more negatively charged. Both sides can then be connected to create a brief electric current as the crystal tries to re-neutralize itself (see Appendix 1a-b for graphic representation). To harness the energy from a mouse moving over a mouse pad using piezoelectricity, we proposed placing piezoelectric transducers directly under the mouse pad (Fig 2). When a mouse was moved over the piezoelectric transducers, the downward pressure of the mouse and the hand on the mouse would apply mechanical stress to the piezoelectric transducers and generate electricity.

The third concept explored the same idea of using piezoelectric transducers, but with the addition of magnets. By placing a single magnet in the mouse and arranging magnets in the mouse pad in such a way that they hit the piezoelectric transducers when the mouse passes over, the magnets would apply concentrated mechanical stress on the crystalline structure as opposed to being dispersed throughout a larger area as in Concept 2.

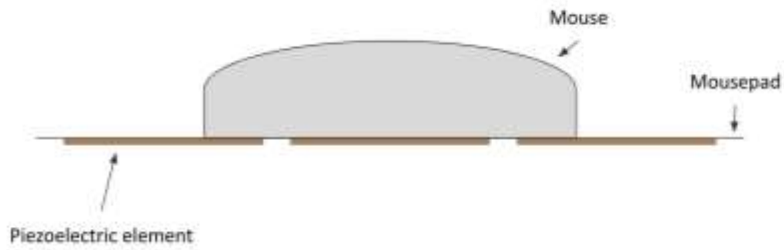

Fig 2: Initial 2D Model (Concept 2)

Within this model arose two possible orientations of the magnets. The magnets in the mouse pad could either be repelled by the magnet in the mouse, causing them to hit piezoelectric transducers underneath them (see Fig 3), or they could be attracted to the magnet in the mouse pad, causing them to hit piezoelectric transducers positioned above them. To determine which formation was more effective, several tests were conducted using a single transducer and a multimeter, and it was found that the attractive force generated a higher voltage. In addition to generating more voltage, the attractive force also impeded the movement of the mouse less than the repelling force. This was counter to our initial expectation that repelling would create an almost lighter mouse feel, however, it was found that attracting generally allowed for more precise mouse movement, whereas repelling created spots that the mouse resisted moving towards.

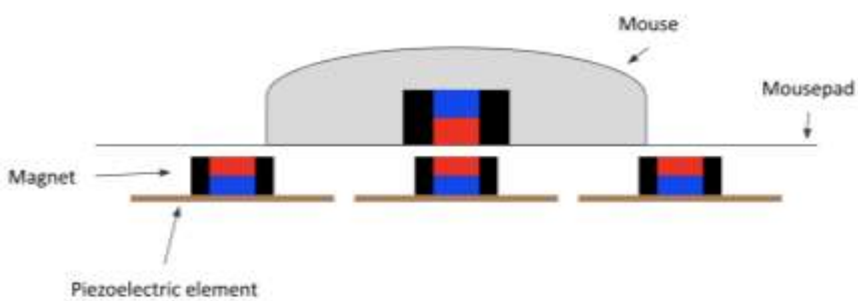

Fig 3: Initial 2D Model (Concept 3)

After discovering that our first concept involving copper coils was not feasible for this project, only the second and third concepts remained. The second model worked as intended, however, it relied entirely on pressure vertical to the mouse pad which is not changing as frequently as the horizontal position. The third model allows for vertical pressure to generate electricity while also allowing for horizontal movement of the mouse to generate electricity as well. As the third model improves upon the design of the second, the final project pursues the third concept.

Design Details

When creating our final design, the most important elements that had to be considered were the placement of the magnets and piezoelectric transducers within the mouse pad, and the size and type of magnets to be used. Because of their relative strength to size ratio, neodymium magnets were selected as the magnet of choice. Magnets with radii of 5mm, 10mm, and 32mm were tested in all possible configurations before deciding on a 32mm magnet inside of the mouse and 10mm magnets inside of the mouse pad. The 10mm magnet was chosen because it contacted the highest percentage of the crystal's surface area while not being too large, and therefore generated the most amount of electricity. The 32mm magnets were chosen for the mouse because they had the largest attractive force. For the placement of the transducers within the mouse pad, it was assumed that the mouse was going to be in the center of the mouse pad most frequently, so a circular array, with the highest concentration of transducers in the center, was decided on as the most effective arrangement to generate the greatest amount of energy (Fig 4).

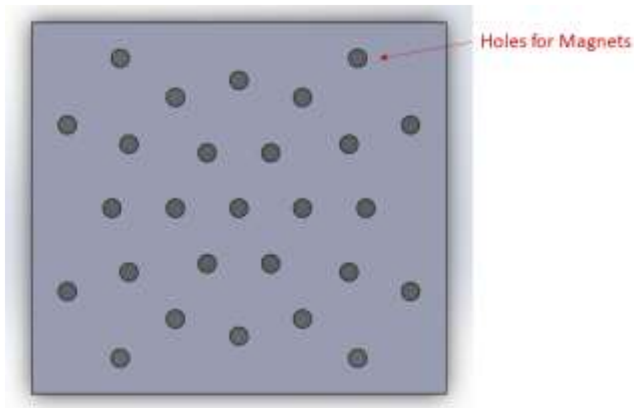

Fig 4: Plate with magnet holes arranged in a circular array

To construct the mouse pad, we determined that it was necessary to have a baseplate for the magnets to sit on (referred to as the Baseplate), a plate on top of the baseplate with holes for the magnets to sit in (referred to as the Magnet Plate) (see Fig 4 above), the piezoelectric transducers on top of the magnets, a top plate above the transducers for the mouse pad to sit on (referred to as the Top Plate), and the mouse pad itself. Due to the raised contacts soldered to the top of the piezoelectric transducers (see Appendix 2), we concluded that when hit, the piezoelectric transducer contacts would make contact with the Top Plate, not the transducer itself. To fix this problem, we decided to attach pegs the same size as the 10mm magnets to the underside of the Top Plate (Fig 5). This ensured that when the magnet in the mouse pad was attracted to the magnet in the mouse, the piezoelectric transducer was squeezed between the magnet and a hard surface, allowing the piezoelectric transducer to generate electricity.

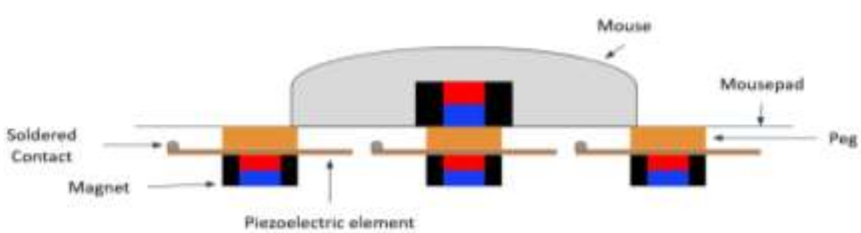

Fig 5: Mouse pad design with pegs

Once the design was decided on, the first step in the build process was to obtain the materials. For the Baseplate, Magnet Plate, and Top Plate, ⅛” (3mm) thick wood was bought from the Northeastern University Bookstore. All other materials were purchased online. After obtaining the materials, the laser cutter in FYELIC (a worker space on campus) was used to cut each piece of wood to 8”x9” (the size of the purchased mouse pad), the holes for the magnets in the Magnet Plate, and the spacers to separate the Magnet Plate and the Top Plate.

The pieces cut out of the holes in the Magnet Plate were used as the pegs. The necessary wood pieces were then glued together using hot glue, the magnets were placed in their holes with the same orientation, and the piezoelectric transducers were hot glued to the Magnet Plate over the magnets (see Fig 6 for initial prototype).

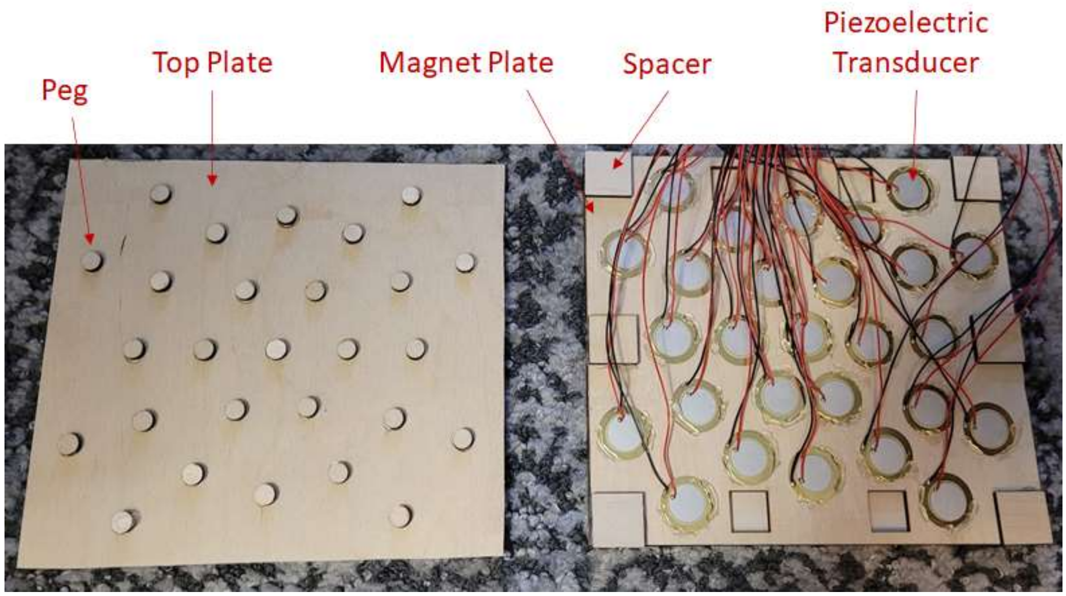

Fig 6: Initial prototype internal structure

However, after some initial testing, it was found that this design iteration was not producing the amount of energy we had expected, which we attributed to an inconsistent amount of force being applied to the crystal because of the magnet hitting the transducer from below. This led us to find that placing the transducers on the pegs with the piezoelectric crystal pointing down (See Appendix 2) produced more voltage when hit with the magnets in the mouse pad than our initial prototype.

We then removed all of the transducers from the Magnet Plate and hot glued them to the pegs. Small rolls of wire were also added as additional spacing as they were the perfect spacing to ensure that the soldered contacts on the transducers did not come into contact with the Magnet Plate (see Fig 7a for final prototype). The last step in the build process was to solder all of the piezoelectric transducer leads to a PCB to make them look cleaner and for ease of connecting them to the Arduino microcontroller used for testing (Fig 7b-c).

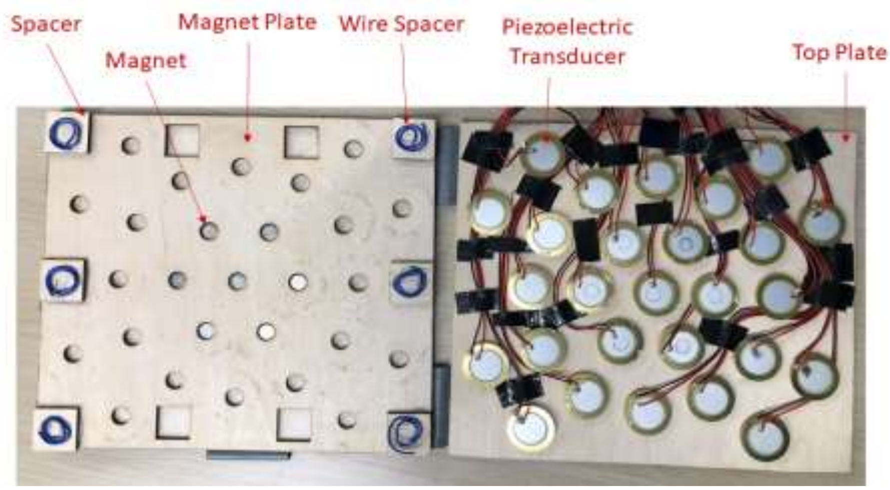

Fig 7a: Final Prototype Internals

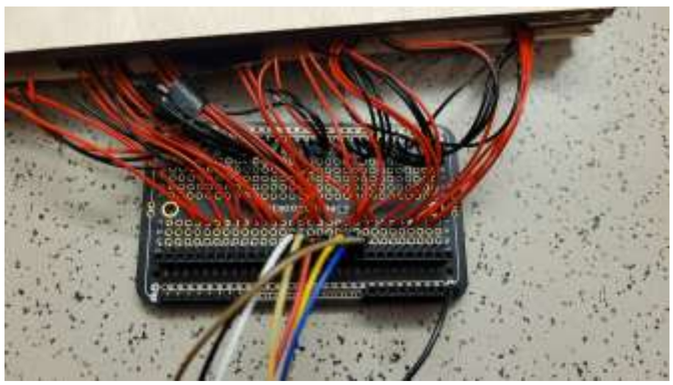

Fig 7b: Transducer wires soldered to PCB

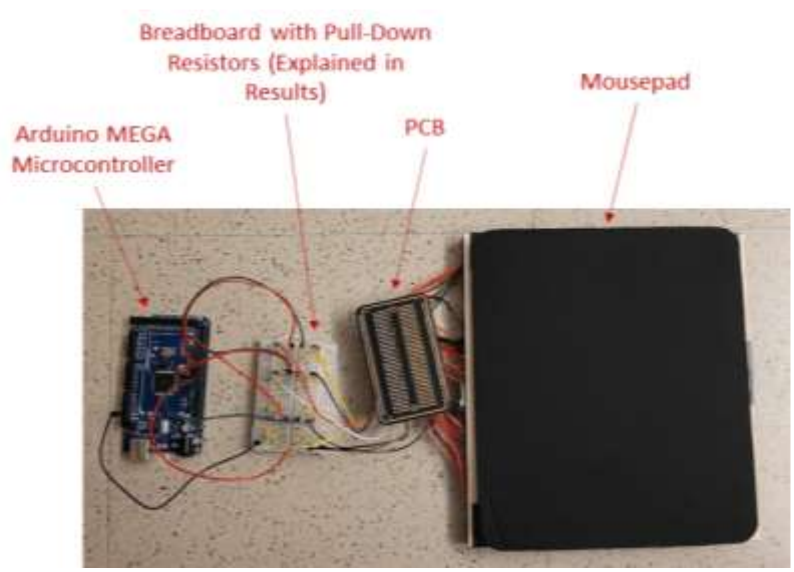

Fig 7c: Completed mouse pad and testing hardware

Testing Methodology

Our data was collected with an Arduino[7] Mega 2560 using two different approaches. The first approach was gathering data directly from the Arduino IDE using the serial monitor and plotter (Appendix 3b). This was an effective way to get preliminary information about the effectiveness of our code as well as the physical setup; however, it was difficult to differentiate data between transducers. Our second testing setup utilized Matlab's integration with Arduino (Appendix 3a). It directly input live data from the mouse pad and generated two different types of graphs: a mesh grid graph and a bar graph. The prior provided the relative electrical potential energy generated at the locations of each transducer. The latter gave us a concrete measurement of the voltage being generated by individual transducers.

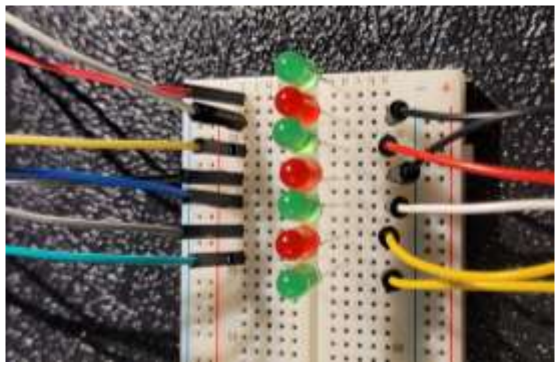

Fig 8: LEDs as diodes

During our initial testing, we found that there were values being displayed by the graphs while the transducers were at equilibrium. Through research, we discovered that we were experiencing floating values through the analog pins. Our first attempt to remedy the issue was by placing a diode between the transducer and the analog pin (Fig 8). We thought that the issue might have to do with the alternating current produced by the transducers, so we limited the current to one direction. This appeared to lessen the issue in testing, but did not altogether fix the problem.

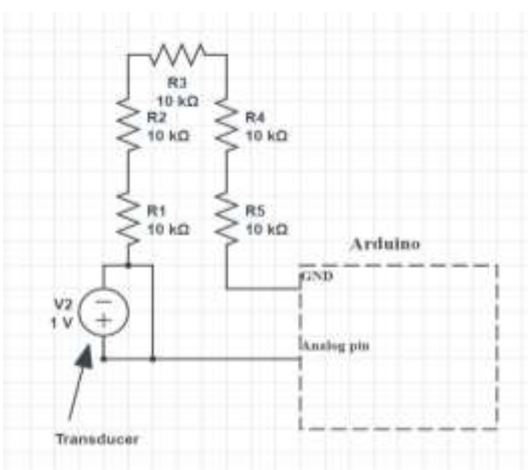

Fig 9: Pull-down resistor

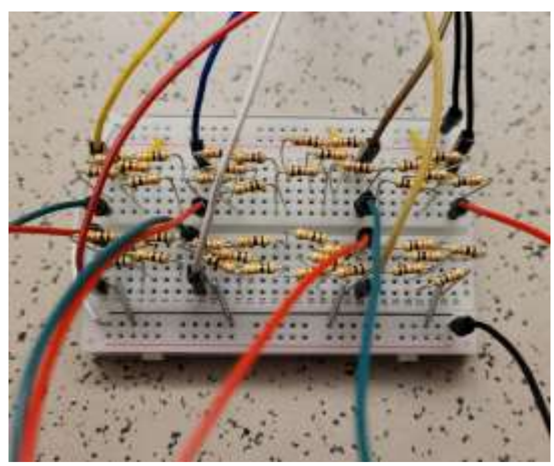

Fig 10: Pull-down resistors on breadboard

After some further research, we implemented the circuit (see Fig 9) shown in Fig 10 to pull the floating values to ground [14]. The circuit acts as a pull-down resistor, connecting the analog pin directly to ground but with added resistance between them. The resistance towards ground means that the majority of the current is directed towards the analog pin, though it does result in dampened voltage readings. Prior to implementing this circuit, it was difficult to differentiate between voltage being generated and floating values created by the Arduino. Afterward, it was possible to identify accurate readings, despite the dampened data.

Results and Discussion

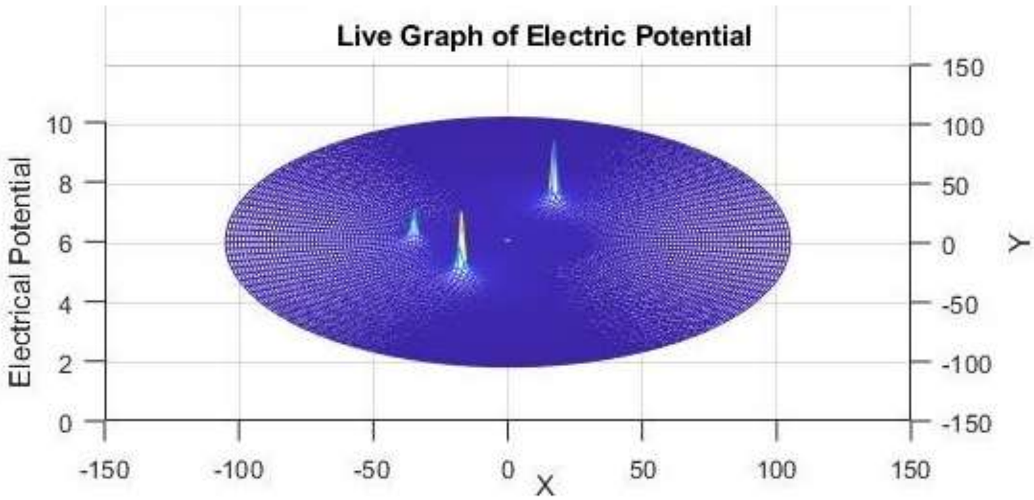

Fig 11: Mesh grid of electric potential energy

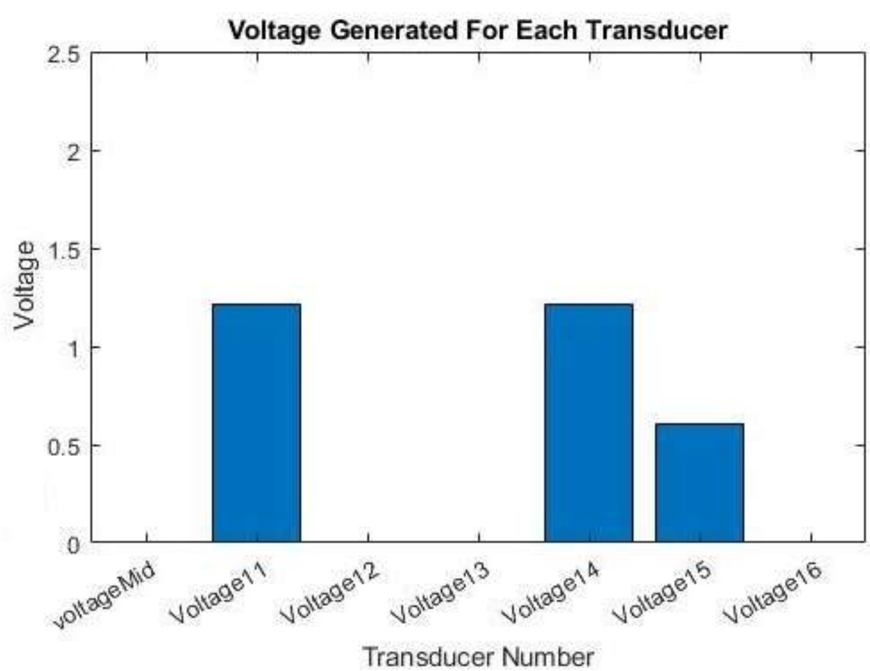

Fig 12: Bar graph of voltages (Multiplied by the constant 124 to account for pull-down resistor damping)

The above graphs (Fig 11 and Fig 12) gave us a good idea of what was occurring with the system, such as where magnets were being stuck and how movement of the mouse correlated with electricity generated. However, the graphs were flawed in that the relatively long refresh time between each data point, a limitation of Matlab, meant that it was missing instantaneous voltage being generated. Unfortunately, piezoelectric transducers create voltage spikes, not sustained current. Therefore, the graphs were missing data from the Arduino because the loop did not read the voltage at the exact moment it was generated.

The graph on the right **(**Fig 12) displays the voltages of the transducers at one instance. The voltages displayed are being multiplied by a constant of 124 to compensate for the resistance created by the pull-down circuit. We came to the constant of 124 by comparing the voltages generated on the Arduino serial monitor with the voltages displayed by a multimeter [15]-[16]. At that moment, it was producing approximately 1.05 V per transducer.

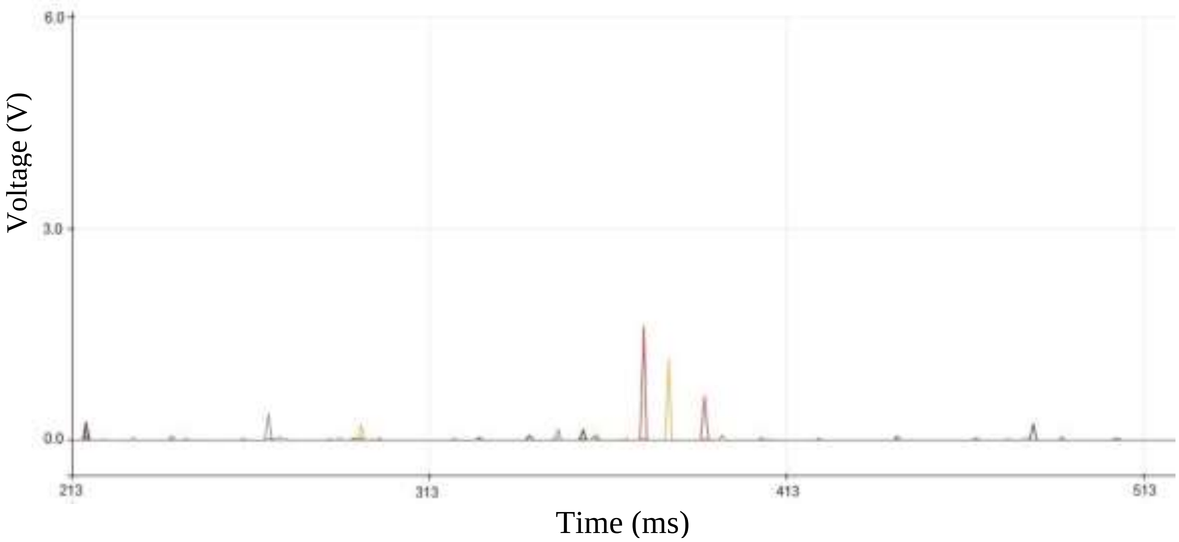

Fig 13: Arduino Serial Plotter not adjusted for resistance

The above graph (Fig 13) shows the unadjusted data displayed via the Arduino IDE's serial plotter. The data shows several spikes as the mouse was moved over the mouse pad with generally relatively low voltages being produced. At the time of recording this graph, only seven transducers were in use.

Conclusion

Our mouse pad was able to generate a decent amount of electricity, producing an average voltage of 1.5V per transducer. In the current array layout, it is expected to contact several transducers at once. Although the exact amount that a user will move a mouse across the mouse pad is unknown, it is estimated that the mouse will be able to produce over 5V, after passing through a capacitor, which is enough to charge a phone or maybe the mouse itself (in the case of a wireless mouse).

To make this product viable for commercial use, various design aspects would need to be improved. In its current state, the mouse pad consists of three different pieces of ⅛" wood that are taped together to allow for easy access to the magnets and piezoelectric transducers inside. This wood would be exchanged for another material to make the mouse pad more durable. This could be a thin rubber material for the backing and hard plastic surface to create a mouse pad that contains the baseplate with the magnets and all of the transducers within this plastic. We also found that it would have been more effective to create a tolerance around the holes in the circular array to prevent the magnets from being stuck. In terms of the product's longevity, dust from the magnets hitting the transducers has left marks on the crystal. It is possible that after extended use, the crystals could break and stop generating electricity. Likely, this issue could be remedied by selecting a more rigid piezoelectric crystal, or by placing a material between the magnet and the crystal to dampen the severity of the impact. This might lessen the electricity generated as a result, but it is something that should be explored.

With just a small amount of optimization and improvement, this mouse pad can be transformed into a product that is ready to be commercially produced and distributed. We believe that this product and others like it have the potential to generate a substantial amount of renewable energy!

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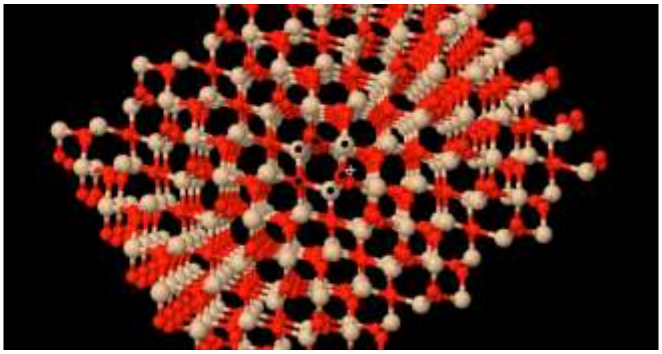
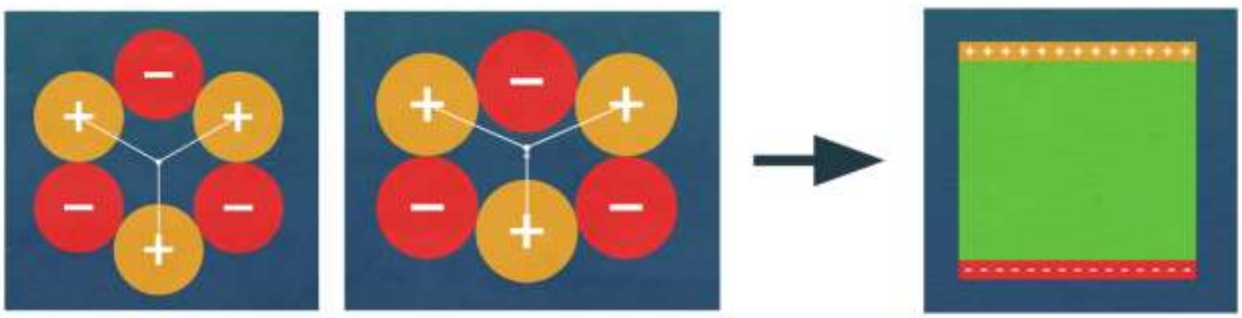
Appendices

Appendix 1:

a. Lattice structure of quartz (SO_2)



b. Compression & electrical polarization of piezoelectric crystal



Appendix 2:

A single piezoelectric transducer:

The center off-white colored circle is the piezoelectric crystal connected to the positive red wire. The metal surrounding it is a copper grounding plate connected to the black ground wire.

Appendix 3:

a. Matlab Code

```
clear
clc
a = arduino()
r = [0:1.5:105];
theta = [0:3:360];
k = 9e9;
[r theta] = meshgrid(r, theta);
x = r.*cosd(theta);
y = r.*sind(theta);
numOfInputs = 7;
temp = zeros([1 numOfInputs]);
Rate = zeros([1 numOfInputs]);
smooth = 0;

%Define the X and Y coordinates of each transducer
x1 = 0; y1 = 0;
x11 = 17.5; y11 = 30.31;
x12 = 35; y12 = 0;
x13 = 17.5; y13 = -30.31;
x14 = -17.5; y14 = -30.31;
x15 = -35; y15 = 0;
x16 = -17.5; y16 = 30.31;

%Calculate X and Y coordinates in polar coordinates
dMid = sqrt((x-x1).^2+(y-y1).^2);
d11 = sqrt((x-x11).^2+(y-y11).^2);
d12 = sqrt((x-x12).^2+(y-y12).^2);
d13 = sqrt((x-x13).^2+(y-y13).^2);
d14 = sqrt((x-x14).^2+(y-y14).^2);
d15 = sqrt((x-x15).^2+(y-y15).^2);
d16 = sqrt((x-x16).^2+(y-y16).^2);


while 1==1
    for i = 1:numOfInputs

        %Read the voltage from each pin
        voltage = 124.*[readVoltage(a, 'A0') readVoltage(a,
'A1') readVoltage(a, 'A2') readVoltage(a, 'A3')
readVoltage(a, 'A4') readVoltage(a, 'A5') readVoltage(a,
'A6')];
        Vmid = (k*voltage(1))./dMid;
        V11 = (k*voltage(2))./d11;
        V12 = (k*voltage(3))./d12;
```

```
        V13 = (k*voltage(4))./d13;
        V14 = (k*voltage(5))./d14;
        V15 = (k*voltage(6))./d15;
        V16 = (k*voltage(7))./d16;

        %Add up all of the arrays to define each point for
the mesh grid
        V = Vmid + V11 + V12 + V13 + V14 + V15 + V16;

        %Create a mesh grid of the position and value of
each transducer
        figure(1)
        cla
        mesh(x,y,V);
        title('Live Graph of Electric Potential')
        xlabel('X')
        ylabel('Y')
        zlabel('Electrical Potential')
        view([0 50])
        zlim([0 10e10])

        %Create a bar graph displaying the current voltage
of each
        %transducer
        figure(2)
        barX = categorical({'voltageMid', 'Voltage11',
'Voltage12', 'Voltage13', 'Voltage14', 'Voltage15',
'Voltage16'});
        barX = reordercats(barX,{'voltageMid', 'Voltage11',
'Voltage12', 'Voltage13', 'Voltage14', 'Voltage15',
'Voltage16'});
        barY = [voltage(1); voltage(2); voltage(3);
voltage(4); voltage(5); voltage(6); voltage(7)];
        cla
        bar(barX, barY);
        title('Voltage Generated For Each Transducer')
        xlabel('Transducer Number')
        ylabel('Voltage (Multiplied by the constant 124 to
account for pull-down resistor dampening)')
        ylim([0 5])
    end
end
```

b. Arduino Code

```
char pinnumber[] = {A0, A1, A2, A3, A4, A5, A6};
int a = 6;
float temp[7]; float temp1[3];
int delayTime = 100;
int x = 0;
float smooth = 0;


void setup(){
  pinMode(A0, INPUT);
  pinMode(A1, INPUT);
  pinMode(A2, INPUT);
  Serial.begin(9600);
  Serial.println(a);
  for(int i=0; i<a; i++)
  {
    temp[i] = 0;
  }
}

void loop(){
  int value; float voltage, Rate;
  for(int i=0; i<=a; i++){
    value = analogRead(pinnumber[i]);
    voltage = (value/204.6);
    Serial.print("Voltage ");
    Serial.print(i);
    Serial.print(" = ");
    Serial.print(voltage, 7);
    Serial.print(" ");
  }
  delay(delayTime);
  Serial.println(" ");
  x++;
}
```