SENG480C/CSC485E Project 2 Report
Earthquake Data Physicalization

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1 Introduction

As residents of Vancouver Island, we live in an active earthquake zone where some of the world's largest mega-thrust earthquakes can be generated. [7] Supposedly, the next "big one" could happen any time between now and 500 years. It is prudent to increase public awareness, and education about earthquakes. When beginning the project and browsing various datasets, we discovered that our own understanding of the earthquake magnitudes is lacking. As members of a scientific academic community, we felt it important that we improve our understanding in this area. We felt that this was clearly a topic which would benefit from innovation in data modelling, therefore, our project is Interactive Earthquake Manipulatives.

We explore the scale of magnitude 5 through 6 earthquakes using a collection of physical model cylinders. The cylinders map volume to joules of energy output for the earthquakes which they represent. To enrich the tactile experience of the manipulatives, they may be used as input for the earthquake simulator which shakes objects according to their volume.

2 Motivation

Throughout this semester we have learned to adapt data and technology to physical objects, to bring human computer interaction into a more intuitive arena for users. This experience mirrors a transformation that has been emerging in society as a whole, and has accelerated in recent years. The importance of data literacy has grown as the vast stores of data have accumulated. It has become increasingly important to ensure our society has data literate citizens. [4]

We feel that being introduced to data manipulatives earlier in our education would have helped us create memories and develop an emotional connection to the topic of earthquakes. [6] Students often struggle to build an intuitive understanding of logarithms using conventional education strategies. Earthquakes are a concrete example of exponential growth that is relevant to everyday life. Our mapping would help students ground the abstract concept of logarithms in the concrete world by providing a visual and kinesthetic approach. This will help prepare them for more complex mathematical processes in the future. [3] Thus, we created this prototype to explore how the topic might be presented in a physical manner to grade 7 and 8 students. Given that the next "big one" could happen any time, it feels important that education, awareness, and interest be developed to prepare for the major event.

3 Implementation

3.1 Physical Models

We initially thought to enable comparison of the models using relative weight, however, distinguishing weight differential is harder to detect than visual cues. [1] Instead, our manipulatives map the energy output of earthquakes in joules to the volume of the cylinders which represent earthquakes from magnitude 5.0 to 6.0. We increase magnitude through this range by 0.1 each time to capture a manageable snapshot of the Richter scale.

Figure 1: Physical Models

Each cylinder has its represented magnitude embossed on the top. To improve the accessibility of our model, we have included braille on the sides of the cylinders so that vision-impaired users may engage with the manipulatives with greater independence. Each cylinder is equipped with a resistor that plugs into our shaker table's motor housing. The shaker table will approximate one axis of shaking according to the magnitude (resistance) supplied.

We determined the radius of our manipulatives by setting our smallest model's volume to $1cm^3$. The height of each cylinder is proportional to its diameter. For each successive magnitude step, we multiplied the previous step's volume by the ratio of energy output between the previous and current step. Then we solve for the radius of the current step:

$$radius = \sqrt[3]{volume/2\pi}$$

The energy (E) output for each magnitude (M) was approximated as follows: [8]

$$\log E = 5.24 + 1.44M$$

To determine the spacing of the braille along the height of each cylinder, we solved for the angle, θ, in degrees between dots based on the arclength between the dots within and between cells of braille:

$$\theta = arclength/radius/\pi * 180$$

To conform with Canadian standards for braille spacing, we use 6.8mm for the arclength between dots in adjacent cells. [9]

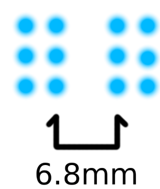

Figure 2: Braille Spacing Between Dots in Adjacent Cells

It is preferable to have the range of models small enough that they may be " ... [seen all] 'at once', requiring less refocusing of the eyes, as well as being easier to manually interact with." [6] As our intended demographic for this prototype is school children in grades 7 and 8 in a classroom setting, the portability of the model seems more important than the wow-factor that a large scale might impress on users. As suggested by García et al. [6], the value of a large-scale model might well fit a different setting such as an installation, museum, or venue such as Science World in Vancouver.

3.2 Earthquake Simulation

The other major system build in this project is a shaking platform that simulates the relative force in various Earthquake magnitudes. This system was built using a combination of electrical circuitry, software control, building blocks and craft materials to construct a proof-of-concept design.

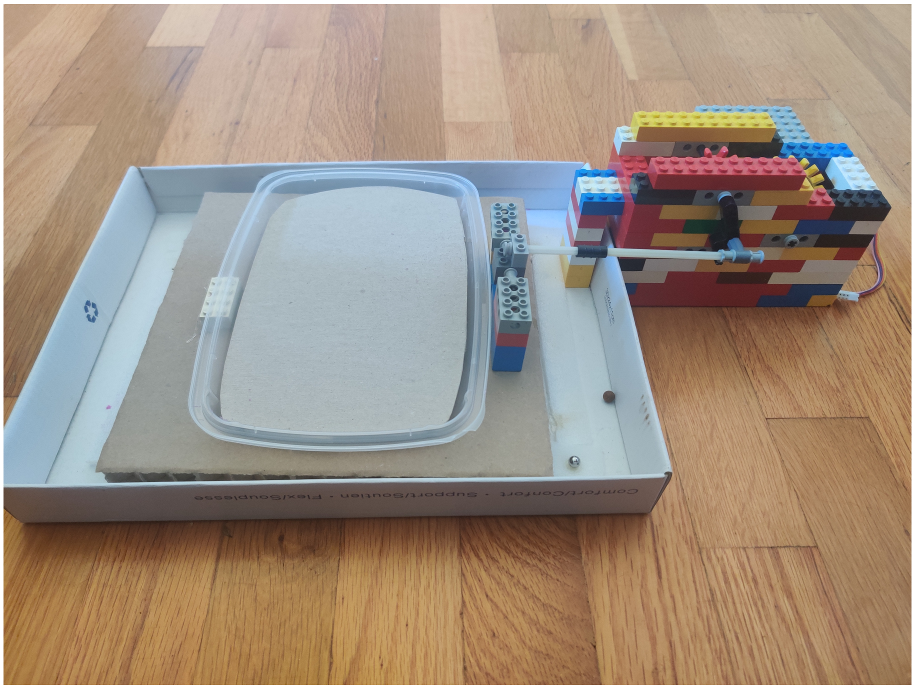

Figure 3: Shaker & Platter

3.2.1 Physical Components

The physical design can be split into two major modules, a shaking platter where a model is placed, and a driver that injects energy into the system. The primary goal of this component is to demonstrate how much damage is inflicted onto a model house given various magnitude earthquakes.

The design of the energy injector was largely influenced by the electrical actuators available to create motion. In the Elegoo kit used for this course, there were only three available motors that had potential to work for this purpose.

1. 5V micro servo motor
2. 5V Fan motor
3. 5V Stepper motor

Each of these motors have their own limitations that made them sub-optimal for this project. The servo motor didn't provide sufficient torque to move a model house since it draws a low current from the Arduino. The fan motor spins very fast, which is useful, but it doesn't make a signal wire for controlling the speed through software. Since the goal is to shake with a variable force depending on what type of earthquake is being simulated, this doesn't work. Lastly, the stepper motor is powerful enough, but it spins at a very slow speed (maximum

15 rpm). That means that the motor could rotate at a maximum speed of one rotation every 4 seconds.

Given the limitations in the motors, the stepper motor was chosen since it was the only motor whose weaknesses could be compensated for in the design. To increase the speed, a series of Lego gears were used. The motor was connected to a shaft with a 23-tooth gear on it, drives another shaft with a 9-tooth gear. This creates a $\frac{23}{9} \approx 2.5$x speed increase. Another 23-tooth gear was put onto the same axle as the small gear to drive a final small gear. This overall creates around a 6.5 times speed increase, bringing the stepper motor to 97.5 rotations per minute.

A rod was connected perpendicular to the final spinning wheel to convert the circular rotation into linear motion. As the rod passes along the bottom of the wheel, the end of the rod is pushed forwards, and when the rod passes along the top of the wheel, the end of the rod is pulled back.

This rod was connected to a platter that contains the model house. Given the motor limitations previously described, the platter was designed to minimize friction and weight. The final design for the platter consist of a shallow cardboard box filled with ball bearings. Atop the ball bearings rests a sturdy cardboard square which has a plastic platter on top of that. The design allows the cardboard/platter combination to easily slide back and forth with minimal friction.

3.2.2 Electronics

The electronics for this project are very simple, consisting of a stepper motor and implementation of an Ohm meter. The stepper motor is powered using an external 9V power supply that connects to the provided breadboard power converter. This connects to the stepper motor control board using the standard specifications.

The Ohm meter consists of three wires and a known-value resistor. As seen in the figure below, an unknown resistor bridges the gap between the power wire and the signal wire. The value of this resistor can then be read in software.

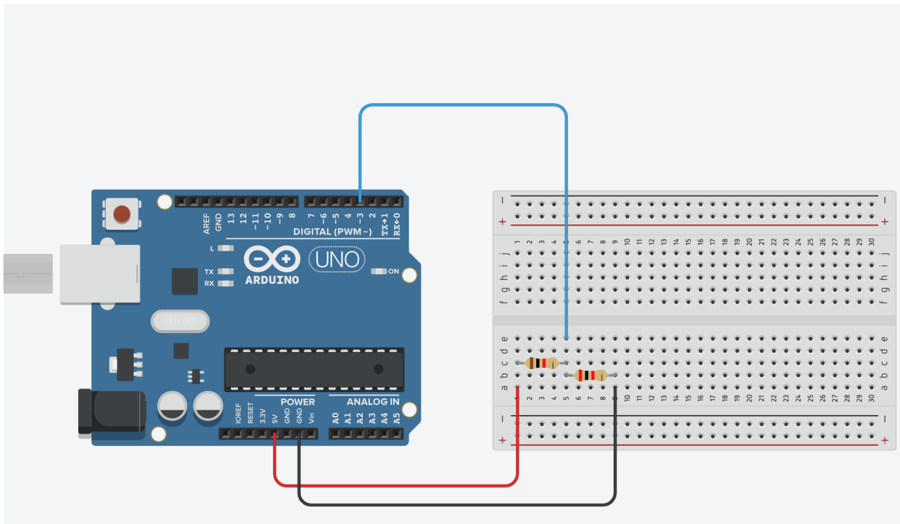

Figure 4: Ohm Meter

3.3 Software

The software for this project is also relatively straight-forward. The software waits idly until a resistor (on the bottom of a 3D-printed model) is plugged into the breadboard. It then reads the value of the resistor to determine which magnitude Earthquake should be simulated.

The software then calculates how fast to spin the motor to accurately simulate the desired type of earthquake. This calculation is performed using the relative energy values for each earthquake magnitude as follows:

$$\frac{MaxEnergy}{CurrentEarthquakeEnergy} * 15$$

Where the maximum energy is the energy of a magnitude 6 earthquake (6.3×10^{13}) the current earthquake energy is the energy of the earthquake currently being modelled and 15 is the maximum rotation speed of the stepper motor.

4 Limitations

Due to the limited resources and proof-of-concept nature of this prototype there are numerous limitations that reduce the accuracy and scope of this project. The first major limitation encountered was caused by the colossal difference in energy between a magnitude 1 and magnitude 9 earthquake. Since there is a 1 trillion times difference in energy, there was no way that our proposed 3D models could encompass all the possible magnitudes of earthquakes.

The 5V motors also hampers the amount of mass that can be used in a model house. This is a physical limitation of the amount of torque the motor can provide to move the platter with a house on it. Originally, this project was going to have two platter/shaker systems so that two earthquakes could be compared side-by-side in real time. However, this was deemed impossible due to the limited time and resources available for construction. Instead, the platter was designed to be detachable so that earthquakes could be simulated sequentially and the results compared.

5 Related Works

While there are many implementations of shaker tables in the world, we did not discover any which had accompanying manipulatives such as our own. Texas A&M University supposedly has the world's largest shaker table, E-Defence, which can shake three story buildings. This project is used by the department of Civil Engineering in collaboration with Nagoya University in Japan, as well as, other Universities in the USA to study the interplay of structural, non-structural and lifeline components in buildings and improve recovery time after disasters. [5] While E-Defence is likely beyond comprehension for our target demographic, it shows how such study is important to drive development of policy, and structural design.

Similar to this work, but at a more intermediate-school scale, there is a shaker table produced by Tinker Crate. [2] This project provides a means for users to play with the structure of their towers to see how they can make them more or less resilient to the shake. However, it doesn't include a variable rate of shaking. The simple design is great for a do-it-yourself kit and does well to shake along 3 axis.

Another study was found that aims to assess how well 10th grade students understand logarithms [3]. This is relevant to our project to determine if a more intuitive system is required to understand the logarithmic Richter Scale. The paper found that students often do not intuitively think of logarithms as numbers but rely more on memorization when solving logarithmic problems.

6 Future Work

In the future, there are many possible extensions and improvements that could be made to this project. First, it would be relatively simple to replace the 5V motor with a 120V equivalent that could create a much larger range of earthquakes. Additional motors could also be added to create movement in two or three dimensions. Realistically, earthquakes sometimes cause the ground to raise or lower along a fault line, which isn't encapsulated in this project.

This project could also be expanded with a larger quantity of real-life earthquakes positioned at their epicenter on a globe. It would interesting to be able to pick up the earthquakes and move them to other locations on the world to see what kind of impact they would have created if they had struck a different place in the world. This is currently out of scope for the project because the impact depends on numerous factors such as the composition of the ground and other geological features. These are not easy to model with the materials available at hand.

7 Conclusion

In this project, a physicalization was created for an Earthquake magnitude dataset. This physicalization aims to improve literacy of youth with regards to understanding the vast scale of earthquakes. In Victoria BC, this is an especially important issue due to the frequency and severity of earthquakes in this region.

To create this physicalization, 3D printed models were created whose volume encapsulates the relative energy of earthquakes ranging between magnitude 5 and 6. These manipulatives provide a more intuitive and interactive scale for earthquake data. A shaking platform was also constructed to give a visual demonstration of the impact of various strengths of earthquakes.

In the future, this project could be extended in multiple ways to improve the scale and accuracy. Given a larger printing budget and more printing time, more models could be created to represent earthquakes outside the range from 5-6. Additionally, a stronger and more accurate motor could be substituted to improve the shaking system to better represent the movement of a real earthquake.

References

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