Designing an Interactive Music Composition Cube

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Abstract. This paper discusses the design of an accessible musical cube and its use in stimulating interest in and understanding of hardware design for college students. The cube uses a custom tilt switch and an accelerometer to generate unique melodies and suggest harmonic sequences.

Keywords: Music composition · Music computing · Accessible Digital Musical Instruments · Computer science education.

1 Introduction

The increasing number of widely-available, low-cost microcontrollers and other music technology has promoted research interest in digital musical instruments (DMIs). Many of these DMIs are developed with the purpose of improving music education. However, DMIs can also be used as a way to teach simple hardware engineering concepts and get students involved in hands-on projects. Research has shown that participating directly in "designing and creating a technologically rich artifact engages students in engineering design in meaningful ways" [10]. In addition, combining music with computer science is an especially effective way to teach these concepts because music "offers a context that appeals to a broad population and enables an equally broad spectrum of personalized projects" [10].

This paper focuses on the motivation and methods for designing and developing an accessible musical cube to both facilitate the composition of unique melodies with pseudo-random environmental interactions and stimulate interest in simple circuitry and technology design. The cube uses an accelerometer and tilt-switch to produce data that is parsed and turned into a melody. An 8-ohm speaker produces the notes in real-time to encourage engagement and create note-level interactions.

2 Motivation

The initial motivation for this research came from a personal experience in a university music theory class that was purely mathematical and lacked any real musical interaction as well as having difficulty composing unique music that is not influenced by already existing music. The idea for the music cube presented in this paper was a device that plays different notes depending on its orientation in order to generate interesting and unique melodies. There is also still a musical interaction so the composer may still feel like they contributed to the creation of the music.

While developing the cube prototype, it was discovered that a tilt switch is a very effective way to demonstrate how simple circuits work. It was found that despite having taken a class on computer systems and circuitry, designing and implementing a DMI project solidified the same concepts in a helpful way. It was found that the bearing ball inside of the tilt switch is a good visual aid to demonstrate how switches can connect or disconnect a circuit, and the audio feedback of different notes helps illustrate how to use simple data for a creative project. This added to the motivation of this project to create a device to facilitate interest and understanding in computer science and hardware design.

In summary, the idea behind the project presented in this paper is the design of a device that uses humans' inherent interest in music and play to help teach hardware engineering and computer systems concepts.

3 Technical Content

The hardware and software components of the completed first prototype are described below.

3.1 Hardware Design

The music box was created by laser cutting clear acrylic squares 7x7cm2 of 3mm thickness and 0.05mm kerf. The cube contains a 5v power supply connected to an ESP32 series microcontroller (ESP32-D0WDQ6). The first box prototype (Fig. 1) used a Teensy 4.0 microcontroller with an on-off switch because of its small size. The Teensy was then replaced by the ESP32 for its WiFi capabilities in order to implement the software designs described below. The microcontroller is connected to a speaker and tilt switch on digital pins, and to an ADXL335 accelerometer on analog pins. The microcontroller, speaker, tilt switch, and power supply are secured with a strong double sided tape.

The initial sensor used to determine orientation was a tilt switch. In order to have many different orientation states for each note in a standard scale, it was necessary to design an eight-sided tilt switch. The idea was to have a cube with each state corresponding to one corner of the cube as shown in Fig. 2. For example, the two red colored pins represent one note that must be played when the freely rolling ball rests against them, thus connecting the circuit.

Several materials were tested in the development of the tilt switch as shown in Fig. 3. The initial prototype (left) was made out of draft board, thin aluminum wire, and a stainless steel bearing ball. However, seeing inside the tilt switch was necessary for testing and a better user experience. Future prototypes were all made with laser-cut clear acrylic with a width of 3mm and kerf of 0.05mm. The second prototype (middle) used the same wire pins as the first which could only be secured with glue. Most superglue contains cyanoacrylate which creates

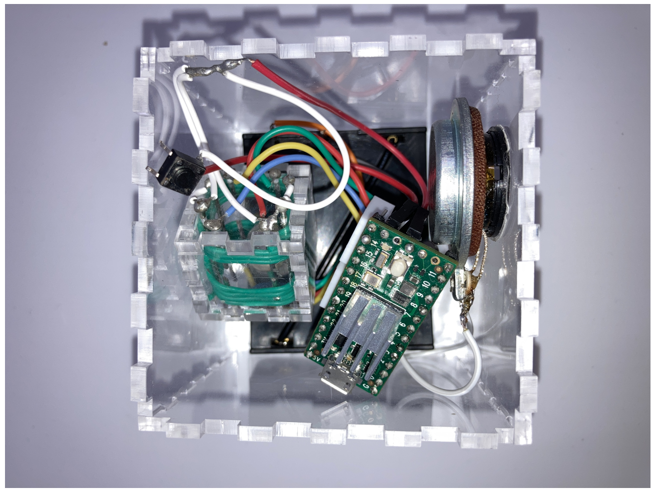

Fig. 1. First cube prototype with Teensy 4.0, tilt switch, 8-ohm speaker, and on-off switch.

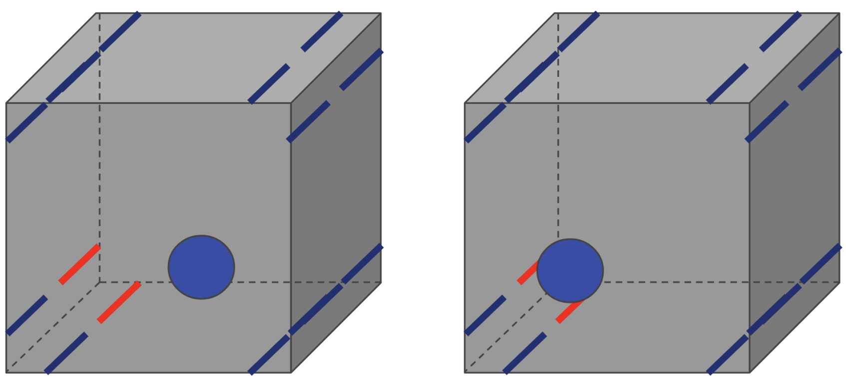

Fig. 2. Tilt switch concept with open (left) and closed (right) circuit configuration.

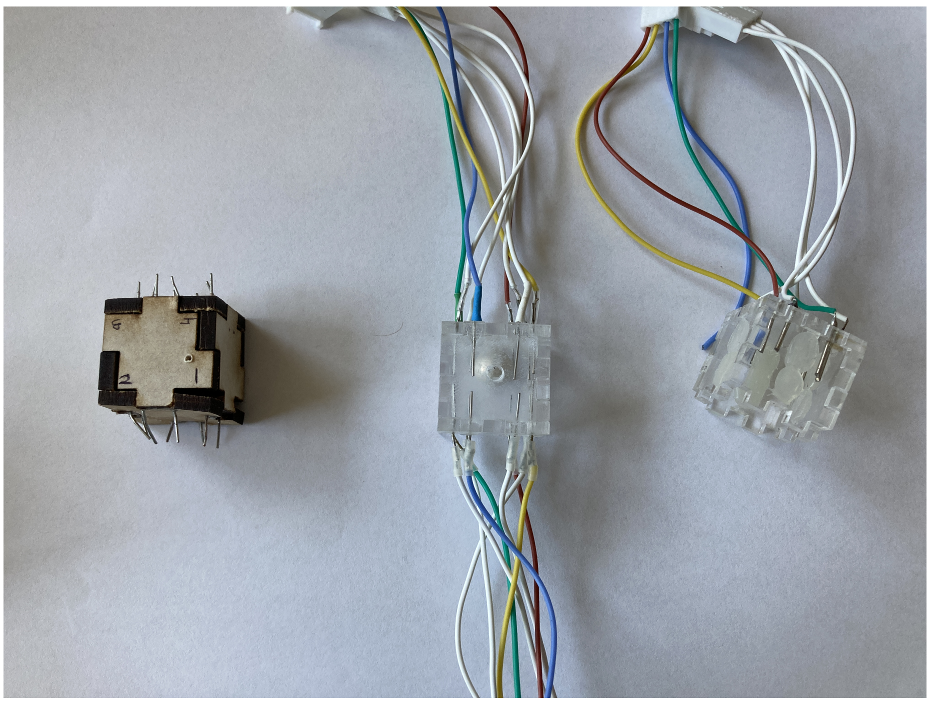

Fig. 3. Evolution of tilt switch design.

a film coating over the inside of the tilt-switch and reduces the conductivity of the wire pins. This led to the third prototype design (right) with larger pins secured by the friction between the pin and acrylic. It was necessary to measure the diameter of the pins and use the laser cutter to cut holes 0.1mm smaller than the diameter to ensure a fit tight enough to be properly secure. Wires can then be soldered to the head of each pin to connect the tilt switch to header pins.

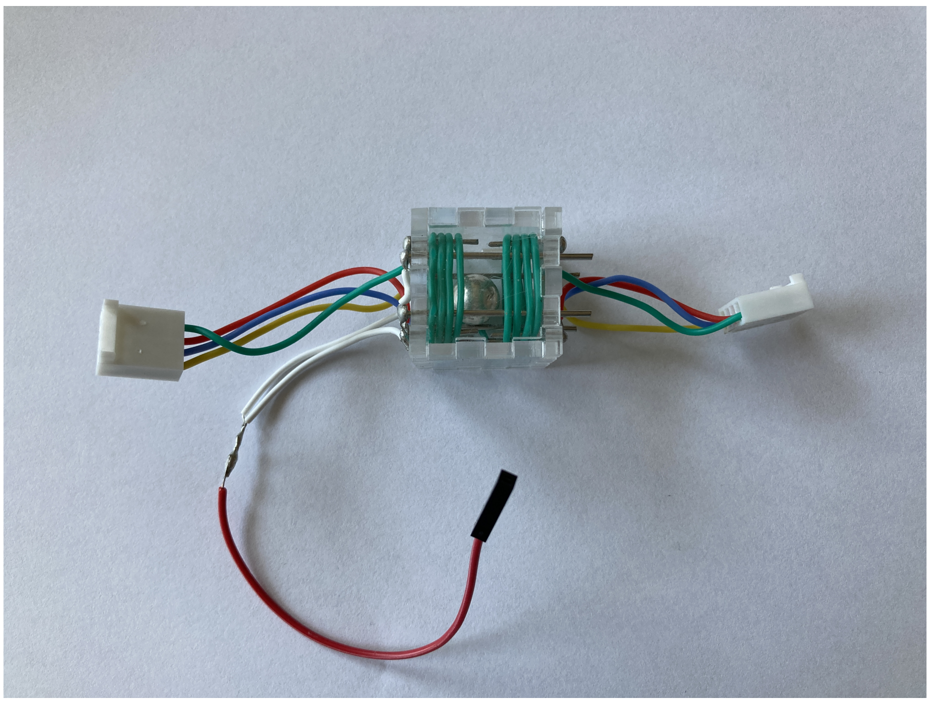

Fig. 4. Final tilt switch prototype.

The final prototype of the tilt switch (Fig. 4) used the same method to secure the pins. However, the space between the pins and the acrylic wall of the box in previous attempts led to the ball getting stuck between two pins and an overall less reliable production of data. A solution to this is visible in the final prototype, in which a green wire is wrapped around the pins on the inside of the box to prevent the ball from getting stuck and ensuring smoother movement between pins.

3.2 Software Design

The motivation for the software design was to create an interface with which the user could receive a more cohesive piece of music than the notes played by the cube.

The two types of data from the tilt switch and accelerometer are dealt in different ways. The tilt switch corresponds to the notes that are played by the speaker. The physical and visual interaction with the tilt switch allows the user to directly hear how their movements are changing the pitches of the notes being played. The accelerometer does not provide audio feedback, but is used instead to generate a melody line and communicate with a harmonic progression suggester. This is done by using the ESP32 to host a web server over WiFi and send processed accelerometer readings to the server as events. The EventSource plugin was used instead of the WebSocket plugin because information only has to be sent one way in a text format.

The data received from the accelerometer is processed into a stream of frequencies correlating to the generated melody, which is then displayed on a web page (Fig. 5). For simplicity, numbers were used instead of roman numeral notation, so harmonies 1-7 refer to triads starting at the given scale degree.

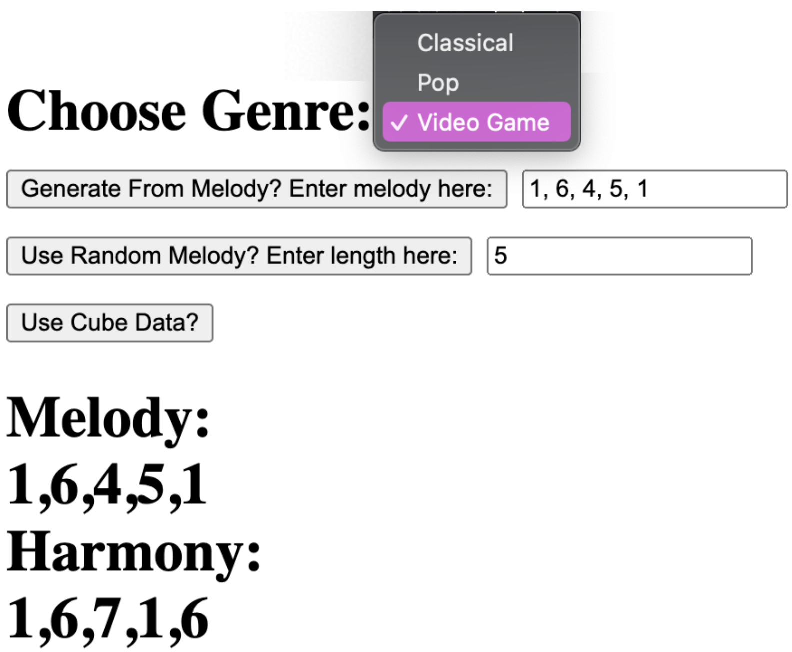

Fig. 5. Webpage with options for genre and melody source

This melody is then analyzed for the scale degree of each note as a basis for which harmony it belongs to. The suggestion of harmony is based on the probabilities of which harmony is most likely to come after any given current harmony. These probabilities are calculated by analyzing the frequency of different chords in several common harmonic progressions (Fig. 6). For example, a dominant seventh (V^7) chord is most likely followed by the tonic (I) or submediant (vi) in a major mode in classical music. The steps for turning a melody into a chord progression are as follows: for each note of the melody, there are three possible triads it can be a part of (for example scale degree 1 can be a part of the I, III, and VI chords. Given the previous harmony, choose the next harmony with the greatest probability from the three possible chords.

$$
\begin{bmatrix}
0 & 0.16 & 0.21 & 0.16 & 0.11 & 0.26 & 0.11 \\
0 & 0 & 0 & 0 & 0.5 & 0 & 0.5 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0.5 & 0 & 0.5 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0.5 & 0 & 0.5 & 0 & 0 & 0 \\
0.76 & 0 & 0.24 & 0 & 0 & 0 & 0
\end{bmatrix}
$$

Fig. 6. Normalized weight matrix generated from major circle progressions where matrix$[i][j]$ corresponds to the probability of going to harmony j from harmony i

Since different genres of music use different types of chord progressions, it was also possible to allow the user to choose a specific genre to imitate with their own melody.

The process for generating weighted probabilities required gathering data about chord progressions used in different types of music. The data for pop and video game music was gathered by consulting different music theory websites [12] [17]. Data for classical music was gathered by generating every possible sequence of up to six chords (without unnecessary repetitions) from a circle progression chart (Fig. 7).

4 Future Work

There are several limitations to the current prototype of this musical cube. The initial goal was to be able to roll it around like a die to generate interesting accelerometer data. However, most plastics, and especially clear acrylic are very brittle and would likely break on impact. Currently, the cube can be rolled around on a soft surface, but would not hold up to repeated impacts or use on a hard floor.

Future work would involve testing out different materials for the outer shell and different ways of securing the components on the inside of the cube to make the device more robust and less prone to breaking. It would be important to

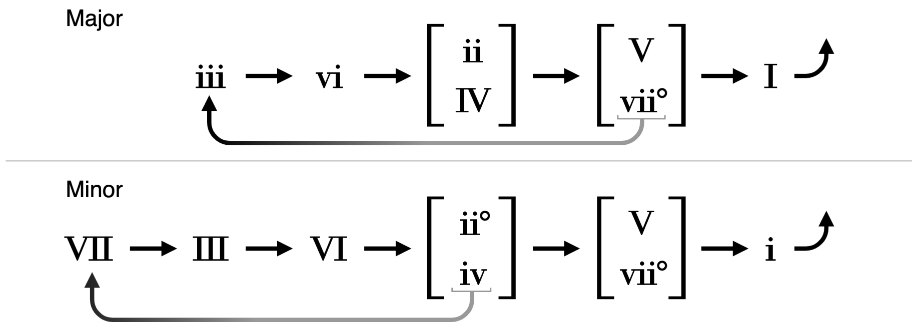

Fig. 7. Major and minor circle progressions

find a solution that keeps the clear outer shell of the cube and the tilt switch because being able to see the hardware design inside the cube is necessary for the proposed use of the device as an educational aid.

To further improve the user experience, it would be beneficial to include more types of visual feedback. For example, lining the inside of the box with led strips that light up with different colors for different notes. It would also be interesting to experiment with different shapes for the tilt switch design. Currently, the data from the tilt switch is also not being used to generate a melody and harmonic progressions (instead the accelerometer data is used for this purpose). It would be ideal if the tilt switch data were also used in the creation of the music displayed on the web page so that the user can draw a connection between how the audio feedback from the cube would translate to a piece of music.

In terms of software design, further improvements can be made by gathering more data for each genre of music, as well as adding new genres. The current web page design is also very basic and could be improved to make the display of harmonic progression and melody more understandable. Lastly, it would also be beneficial to include an option to listen to the suggested harmony; this would allow the user to better understand the connection between the data generated by the cube and the resulting music.

Currently, the type of communication between the microcontroller and web page is a one-way text message. A possible improvement would be to implement the previously discussed idea of providing audio feedback of the accelerometer data by sending the data back to the microcontroller and playing the generated harmonic progression from the device itself. This would be a better way to implement audio feedback because it would keep the feedback contained within the device.

In terms of musicality, the web page currently only produces harmonic progressions from basic diatonic triads. Most music is not limited in this way, so it would be more accurate in data collection, probability generation, and progression suggestion to include applied chords, seventh chords, and other types of chords.

5 Related Work

Because of the wide availability of resources and low-cost hardware needed for digital music instruments, there are many DMIs similar to the one discussed in this paper. The PETECUBE is a similar interactive cube focused on incorporating multi-modal feedback equally between touch, sight, and hearing [2]. The PETECUBE produces vibrations for haptic feedback that simulates the feeling of a drum vibrating, a visual simulation of the cube on a monitor that can be seen in 3D to enhance user experience, and playback of audio through speakers.

LoopBlocks is a project focused on designing an accessible musical interface for children with intellectual disabilities. The instrument is built from a rectangular wooden frame with indentations in the top where wooden blocks fit and trigger different musical events. LoopBlocks allows children to explore making music by experiencing rhythms and patterns by aiming to reduce the cognitive load required to play traditional instruments.[6]

A study presented by Trappe (2012) describes the results of creating a graphical user interface (GUI) and running a music technology workshop with primary school students. A pre-test was run to determine which aspects of graphical programming languages (specifically Pure Data) made tasks more difficult for the children. Using these findings, a GUI was created to replace the text blocks with color-coded and easy-to-understand icons (i.e. a speaker icon or a note icon). A workshop was then run twice a week for five weeks in which children worked together to create different wearable musical instruments. It was concluded that providing an interactive musical project was an effective way to teach children about sound and instrument design because it allows children to play in a controlled and educational environment.

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