CubeHarmonic: A New Musical Instrument Based on Rubik's Cube with Embedded Motion Sensor

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(a) (b) (c) (d)

Figure 1: (a): CubeHarmonic (b): IM3D markers inside. (c) and (d): Play music with CubeHarmonic.

ABSTRACT

A contemporary challenge involves scientific education and the connection between new technologies and the heritage of the past. CubeHarmonic (CH) joins novelty and tradition, creativity and education, science and art. It takes shape as a novel musical instrument where magnetic 3D motion tracking technology meets musical performance and composition. CH is a Rubik's cube with a note on each facet, and a chord or chord sequence on each face. The position of each facet is detected through magnetic 3D motion tracking. While scrambling the cube, the performer gets new chords and new chord sequences. CH can be used to compose, improvise,[1] and teach music and mathematics (group theory, permutations) with colors and physical manipulation supporting abstract thinking. Furthermore, CH allows visually impaired people to enjoy Rubik's cube manipulation by using sounds instead of colors.

CCS CONCEPTS

• **Applied computing** → **Sound and music computing**; Performing arts; • **Human-centered computing** → **Sound-based input / output**;

KEYWORDS

magnetic 3D motion tracking, permutations, chords, tonnetz

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[1]Music professionals, especially in the areas of composition and improvisation, can enjoy the cube as an additional tool for their practice.

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1 INTRODUCTION AND RELATED WORK

CubeHarmonic[2] (CH) is a Rubik's cube with notes on each facet and chords on each face [Mannone et al. 2018; Mazzola et al. 2016], combining music theory (chords), mathematics (permutations, combinatorics, and group theory[3]), and technology (motion tracking). As musical chords are simultaneous superpositions of three or more notes, mixing the notes of a few chords can lead to different combinations. Chord changes may abide to harmony rules, such as voice leading, but they can also be more freely and creatively explored. We base our work on the combination of two theoretical fields. On the one hand, music theory, which studies chords and chord sequences. One the other hand, mathematical combinatorics studies *how many* combinations of given elements are possible, and which transformations (in our case moves) are necessary to reach them. In fact, the Rubik's cube embodies mathematical concepts in a tangible device. Interest in joining mathematics and music is witnessed by several studies [Mazzola et al. 2016; Tymoczko 2006], and even games such as Mozart's dice game [Mazzola et al. 2016] that exploits groups and combinatorics. With CH, students of music or mathematics may enjoy and profit from tangible references and visual/sound examples. We are developing CH as a real musical instrument, based on magnetic motion tracking and screen projections [Mannone et al. 2018]. Through motion tracking, we identify the position of each facet, then map them into sound. Being theory-based, allowing pitch permutations and 3-dimensional tangible (or virtual, as in the screen) interface, and using motion tracking, CH differs from other music technologies.[4] CH also allows to play

[2]Thought by M. Mannone in 2013, and first published in 2016 [Mazzola et al. 2016].
[3]A group is given by a set and a binary operation that, taken two elements from the set, gives a third element of the set, verifying some properties: associativity, closure, identity, and invertibility.
[4]Such as http://808cube.com/ or https://block-jam.en.uptodown.com/android

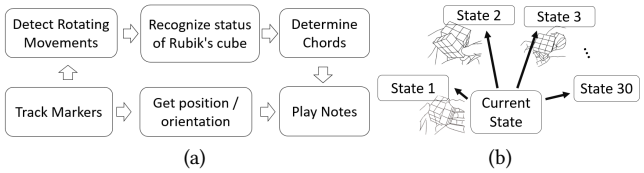

Figure 2: Implementation of CubeHarmonic. (a) Workflow and (b) state transition mechanism in CubeHarmonic.

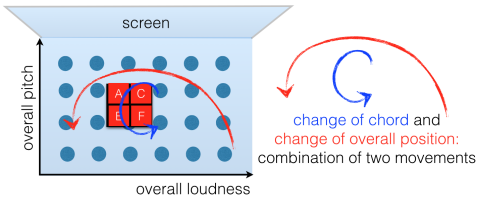

Figure 3: Movements and musical outputs

with continuous or discrete pitches. Performer's control, jointly with crossmodal effects between sounds, images on screen, and performer's movements, makes CH different from other Rubik's cube-like tools [Polfreman and Oliver 2017].

2 IMPLEMENTATION OF CUBEHARMONIC

By using magnetic 3D motion tracking (IM3D), CH tracks facets' motion and combination, and then plays the notes mapped to a particular face. IM3D tracks 3D positions of multiple small, lightweight, wireless markers (LC coils) with unique IDs in real-time [Huang et al. 2015, 2014]. We embed the markers into a 3×3×3 Rubik's cube's corner and center facets to track the scrambling motion (Fig. 1 (b)). With outputs from IM3D, a 3D representation of the Rubik's cube is recognized and CH applies a finite-state machine mechanism (Fig. 2 (b)) to indicate facets' combinations. As shown in Fig. 2 (a), our system starts from an initial state, detects Rubik's cube's rotations, and recognizes its status. Each facet is mapped with a specific musical note, and the combination of the facets of the Rubik's cube construct chords, one per face. The system plays notes on the top face using pre-produced loop sounds; then, by scrambling the physical cube, we can play music. Notes can be set in advance, according to the piece's harmonic complexity and to match the tuning of other instruments the cube is playing with. We can map the cube's position on the horizontal plane into both overall pitch and overall loudness changes within a given range (Fig. 3). Because notes mapped on the facets between tracks can be changed, CH doesn't require physical cube solving.

3 SOCIAL IMPACT

CH, by joining multisensorial technologies, mathematics, and music, helps us thrive across challenges in creativity, pedagogy (of mathematics and music), and disability studies. The exploration of a large amount of possible combinations out of a few initial notes, and the association between an aesthetic result with physical manipulative activity, both contribute to enhancing creativity. Disability studies can involve a specifically-designed CH with one color → one pitch associations, allowing visually impaired people to use sounds to solve the cube. Concerning mathematics, Rubik's cube is based on permutation groups: the facets are the set, and their possible permutations (moves) are the group operations. Sets of moves on the cube constitute subgroups of the Rubik's cube, and all possible moves give its group [Zassenhaus 1982]. Faces and their rotations are indicated with letters [Hutchings 2011; Zassenhaus 1982]. We can use these notations for CH as a guitar tablature. Instead of replacing a single note of a chord, by using CH it becomes easier to exchange cube layers with a rational or ear-guided sequence of moves. Students can enjoy rotations along with their inverse and their musical effect, while music professionals and mathematicians can more rationally explore CH guiding students, e.g., in a classroom setup. Key concepts are: tonnetz,[5] tonnetz on a cube, tonnetz transformations locally preserved on a cube, and chord-preserving symmetries of the Rubik's cube. The cube's rotational symmetry helps perform cyclical progressions of chords: after specific sequences of moves, we return to the same chords. Our perceived symmetry can change: a rotated face gives the same sound of the un-rotated face if its notes are played at the same time (harmonically); it gives a different sequence of sounds if notes are played one after the other (melodically).

4 CONCLUSIONS AND FUTURE WORK

CubeHarmonic is a novel musical instrument joining technology and musical knowledge, and it may help us thrive in a STEAM framework. Future works include new musical uses as a creative interface. Future technical improvements involve: single note selection to play melodies and musical functions (timbre and MIDI output) enhancement. Customizable parameters, initial note setting without coding, and simultaneous vision of all cube's faces via different projections on the same user screen to more easily predict rotations outcomes will enhance the cube. Moreover, we aim to investigate impact of CH toward students and people with visual impairments. Finally, performers' movements can be recorded to create compositions with sequences of moves on the cube.

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[5] A lattice of notes and their connections constituting chords [Tymoczko 2006].