C2C as Tangible Interface for Interaction, Navigation, and Control in Digital Systems: An Interaction Design Approach Using Cube as Interfaces

Mukil Kumar [a], Anoushka Shome [b], Samiksha Sidharth Gajbhiye [c], Prajakta Hardikar [d]
Guided by Prof. Jayesh Pillai, Prof. Venkatesh Rajamanickam

[a,b,c,d] *1st Year, Interaction Design, M.Des, Industrial Design Center, IIT Bombay*

ABSTRACT

This study presents the design and development of **C2C**, a pair of tangible interfaces aimed at enhancing interaction, navigation, and control within digital systems. Conceived as part of an exploratory module in interaction design, the project began with open-ended ideation focused on the creative possibilities of tangibility. Drawing inspiration from the Infinity Cube toy—known for its endless manipulative configurations—our team explored how such physical affordances could translate into multi-functional digital interactions. This initial vision was refined to create a more focused, non-overwhelming interaction model, balancing expressive control with intuitive usability.

The resulting **C2C** integrate rotary encoders, tactile buttons, and onboard displays powered by microcontroller, leveraging their full capabilities. Functional features include real-time file navigation, interactive visual feedback, delight animations, and embedded tools such as Pomodoro timers for task and presentation control. The devices also support lightweight gameplay and display interactions, expanding their use beyond traditional input devices. Through this project, we explore how tangible, modular interfaces can serve as versatile tools for digital interaction, offering a user-centric alternative to conventional screen-based controls.

KEYWORDS

Microcontroller Unit (MCU), Tangible Interfaces, Rotary Encoders, User Experience (UX), Interaction Design, Digital Manipulation, Human Interface Device (HID), Embedded Systems, Exploratory Prototyping, Feedback Animation, Pomodoro Timer, File Navigation, Playful Interaction, Human-Computer Interaction (HCI), Display-Based Interaction, Iterative Design, Modular Design, Delightful Feedback, Command-Line Interface (CLI), Integrated Development Environment (IDE), UNIX Systems, Compiler Design, Control Interfaces, Low-Tech, High-Tech, Tangible User Interfaces (TUIs).

1. Introduction

This study presents C2C, a tangible interaction system developed as part of an academic module focused on exploratory prototyping and interaction design. The project investigates how physical form, embedded computation, and expressive input modalities can enrich user interaction within digital environments. The work is situated at the intersection of tangible user interfaces (TUIs) and human-computer interaction (HCI), with the goal of creating a compact, modular interface that enables intuitive control, playful engagement, and system navigation.

The ideation phase began with an open-ended exploration of physical metaphors, ultimately drawing inspiration from the Infinity Cube—a folding toy that evokes ideas of continuous manipulation and dynamic control. This led to the conceptualization of C2C as a pair of interactive cubes that invite users to engage with digital systems through rotary encoders, tactile buttons, and visual feedback provided via onboard OLED displays.

Designed with a balance of technical precision and creative intent, each unit of C2C supports multiple modes of interaction, including file navigation, Pomodoro-based time management, presentation control, and micro-game engagement. The system utilizes embedded microcontrollers, offering real-time feedback through animations and state transitions that support both function and delight.

To maximize interoperability and ease of integration, C2C is implemented as a Human Interface Device (HID), enabling seamless communication with various operating systems, including Windows, macOS, Android, and iOS. This cross-platform compatibility ensures that the system can operate without the need for additional drivers or proprietary software, further underscoring its versatility and user-friendliness.

As an outcome of an academic design module, this work reflects a strong emphasis on iterative design, system integration, and user-centered exploration. It contributes to ongoing discussions in tangible computing by demonstrating how small-form, tangible devices can effectively mediate digital tasks while enhancing engagement through physicality, modularity, and responsiveness.

2. Literature Review

Tangible User Interfaces (TUIs) have become a significant area of exploration in Human-Computer Interaction, especially for their capacity to bring physical affordances into digital interaction. Within this domain, cubic shapes have consistently emerged as compelling interaction forms due to their symmetrical geometry, ease of manipulation, and potential for multi-faceted input/output mapping.

In *“A Display Cube as a Tangible User Interface”*, Matthias Kranz, Albrecht Schmidt, Dominik hcilab and Holleis investigate the cube not merely as a passive tangible controller, but as an active and dynamic interactive device. Their prototype integrates displays on all six sides of a cube, transforming it into a portable and reconfigurable interface. The study explores how rotation, face detection, and spatial manipulation can be combined with visual feedback to create novel interaction techniques. By leveraging the cube’s physical orientation and face-specific information, the system enables intuitive navigation through digital content, fostering a more embodied and spatial mode of interaction. Their work also discusses practical applications in collaborative environments and personal information management, highlighting the cube's potential for mobile and context-aware interfaces.

Complementing this perspective, Lefeuvre et al. in *"Bricks, Blocks, Boxes, Cubes, and Dice: On the Role of Cubic Shapes for the Design of Tangible Interactive Devices"* offer a broader theoretical and design-oriented analysis of cubic forms in TUI design. Their study categorizes various use cases of cubic devices, highlighting how their geometry supports modularity, stackability, and spatial mapping. The research identifies cubes as ideal for encoding multiple modes of interaction through their faces, edges, and vertices. Moreover, the authors argue that cubic shapes are particularly suited for spatial cognition and mnemonic strategies, enabling users to associate digital functions with physical sides or arrangements. They emphasize the cube's ability to support both direct manipulation and metaphorical mappings, making it a versatile form factor in tangible interaction design.

Together, these studies underscore the cube as a powerful object in the design of TUIs—balancing physical familiarity with rich interaction possibilities. Their findings lay a conceptual and technical foundation for using cubic shapes in the creation of embodied, spatially aware, and contextually adaptive interfaces.

2.1 Properties of cubes as tangible interactive devices

Since the late 1970s cubes have been popularly used in tangible interaction design as tangible input devices and IoT devices. There are some properties of cubes that make them such an ideal choice for designers. These properties can be interdependent as well, and also be dependent on whether it's a one cube or a multiple cube system.

Due to its ninety-degree angles, a cube easily represents the three axes (x, y, and z), thus enabling itself to be used as a tool to change orientation in space and virtual 3D environments. Its orientation and placement with respect to other cubes in the same environment can form a source of input. Due to its opposite, parallel faces, cubes are easy to stack and juxtapose. Complex forms can be made by stacking smaller cubes. Having six distinct faces, each with equal dominance, affords the cube to have six different functions, one on each face. Adding to this, a side can be chosen randomly, thus enhancing the playfulness of a cube. Having a set of cubes allows for multiple functions with some variation, while they can be similar in terms of how to use them. A user may need to learn only one cube, and can learn the other cubes' interaction very fast due to the similarity to the first cube. Cubes are easy to produce considering the ninety-degree angles and equal sides.

2.2 Related work

2.2.1 i-CUBE

The i-Cube is an interactive, cube-shaped digital tool designed to help users explore and understand 3D spatial relationships by sensing its own faces and the positions of nearby i-Cubes. The i-Cubes can be arranged in multiple ways to enact different functions. For example, arranging them in a linear way could lead to music being played by an instrument in a sequence of different notes.

A total of seven i-Cube units were used in the prototype setup. These i-Cubes maintain continuous wireless communication with a host PC, which operates in the background and does not participate in the hands-on interactive play.

The PC is responsible for calculating the current 3D face and orientation relationships between the i-Cubes, running sequencing algorithms, and handling the mixing and playback of multiple layers of stored musical sequences.

The distribution of the cubes is as follows: One acts as the Mode Selector (MS), allowing users to choose from six operational modes—PLAY, STORE-NEW, STORE-APPEND, TEMPO, COLOR, and RESET—by flipping the desired face to the top. Another cube serves as the Instrument Selector (IS), used to pick from six instrument types, including percussive (e.g., Latin percussion, bongos) and melodic (e.g., piano, flute, bell, guitar). Both the MS and IS cubes are labeled for easy identification, and built-in accelerometers detect face orientation based on tilt. The remaining five unlabeled cubes are Musical Element (ME) cubes, used to build musical sequences. Each ME cube offers six different sounds; for instance, with the piano setting, notes from A to G are distributed across the 30 faces of the five cubes.

2.2.2 The Learning Cube

The Learning Cube is a unique educational tool that looks like a physical cube with a screen on each of its six sides and a speaker inside. It has an embedded system that controls these features. When the cube is opened, you can see the hardware and wires connected to the displays. When closed, it can be used for various quizzes and tests. The cube is designed for all ages, allowing users to pick it up, shake it, and interact with it like a game. Since it functions similarly to dice, users expect different information on each side, which can be text or images.

One of the cube's main functions is a multiple-choice quiz system. Each time, users see one question on the top display and five answer options on the other sides, with one correct answer among them. Users simply rotate the cube to the side with the correct answer and shake it to confirm their choice. If they answer incorrectly, they can try again. This basic setup allows for various applications, such as a vocabulary trainer that displays a word to translate and quizzes that challenge users to match objects from different views.

3. Methodology

3.1 Ideation

3.1.1 Infinity cube as tangible interaction

An Infinity Cube is a mechanical puzzle toy that revolves around mathematical concepts. Its design resembles a 2×2 Rubik's Cube and can be disassembled and reassembled from various angles, resulting in a visually captivating effect.

Initially the thought was to include any two bi-directional interactions (like zooming and scrolling) using an infinity cube. The direction of rotation would determine the direction of action. It is shown in the fig. 1 below.

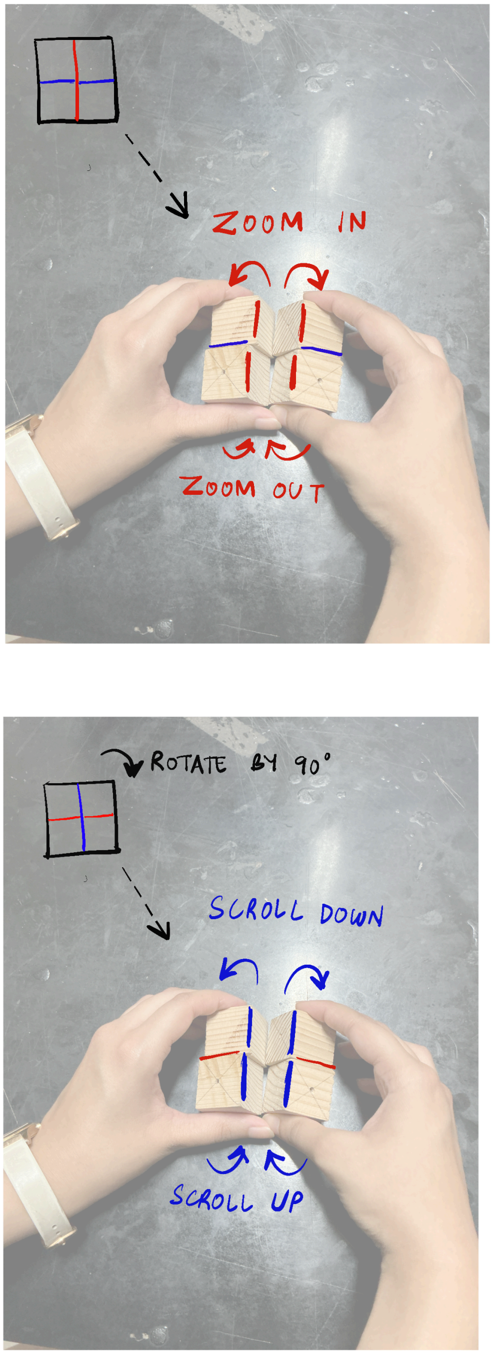

Fig 1. Cube combinations and associated functions

3.1.2 Dual cube structure

Due to the complexity of the infinity cube and limited time, the project was scoped down to interactions with just two cubes - with one cube being tech-intensive(consistes all electronics) and the other cube being low tech but holding the key to most of the functions. Both the cubes would have to be physically joined in order to register the function which is there at the joining face of the low-tech cube, and the low-tech cube could then be rotated to vary that function in a particular direction. The high-tech cube would also contain buttons for confirmatory actions. Both cubes would use magnets as a snapping tool.

We decided to use the cubes to interact with a digital photo gallery. We came up with a list of functions, and how we could integrate them into a two cubes system (given below)

Select: Rotate (move back and forth) + tap button (confirm)
Multiple select - random: Rotate (move back and forth) + tap button (confirm)
Multiple select - series: Tap button on starting image + rotate (move till last image) + tap button on the last image
Delete: Rotate (move back and forth) + tap button + tap button (once to select an image and once to confirm deletion)
Scroll: Rotate (scroll up and down)
Zoom: Rotate (zoom in and out)
Preview: Double tap button

Additionally, the tech-heavy cube could also be nailed to a stand on the table so that the user can use the system with just one hand.

3.2 Feasibility (sensors, electronics requirements)

The feasibility of developing a cube-based tangible interactive device was extensively explored through the integration of hardware components, firmware development, and cross-platform testing. The goal was to create a functional Human Interface Device (HID) capable of supporting spatial and tactile interactions across multiple systems.

Microcontroller Platform

The core of the system is built around the RP2040, a dual-core ARM Cortex-M0+ microcontroller. This MCU offers high-speed performance with low power consumption and is well-suited for real-time interaction processing and USB HID capabilities. Its native support for QMK (Quantum Mechanical board firmware) also allows for customization of input behavior and device-layer management.

Sensors and Components

To support interactive and rotational inputs, the following sensors and electronics were used:

- **Hollow Shaft Rotary Encoder**: Enables precise detection of rotation, which is crucial for face-switching and directional input based on cube movement. The hollow shaft variant allows easy alignment with the cube's axis in the project, we assigned the encoder as a primary continuous input device.

- **Tactile Push Button Switches**: Embedded on cube faces or corners to capture discrete presses. These allow users to select, activate, or confirm interactions through physical input and switch between layers.

- **Neodymium Magnets**: Used for **magnetic coupling** to facilitate modular connections between cube components or for aligning detachable modules. This enables reconfigurable physical interfaces and enhances the tangible nature of the device.

Firmware and Development Tools

The device was made functional as a USB HID using the **QMK firmware**. Development and configuration were done via:

- **QMK CLI (Command Line Interface)**: Used for building, compiling, and flashing firmware to the RP2040.

- **Unix-based MSYS for Windows** and native Unix/macOS environments: Both platforms were utilized to compile and flash QMK firmware, ensuring cross-platform compatibility.

The firmware is primarily written in **C**, with supporting files in:

- **.h (header files)** for declarations,
- **.c files** for logic implementation,
- **.mk files** for build instructions, and
- **keymap.json** for layout and behavior configuration using QMK Configurator or CLI tools.

Cross-Platform Functionality
During prototyping and testing, the device was verified to work seamlessly across:

- **Windows**
- **macOS**
- **Android (via USB OTG)**
- **Linux(Ubuntu)**

This cross-platform compatibility confirms the technical feasibility of the device as a universal HID, capable of supporting varied workflows in tangible interaction contexts.

3.4 Prototyping
The prototyping phase involved multiple iterations to refine both the form factor and functional integration of the cube-based interactive device. Each stage contributed

valuable insights into ergonomics, material suitability, and the feasibility of incorporating electronic components within a compact cubic structure.

3.4.1 Form Exploration With Wood

The process began with wooden blocks as given in the given picture (Fig.2), which served as the initial medium for exploring the tactile and spatial qualities of the cube form. This phase was purely conceptual and aimed at understanding how users might hold, rotate, and interact with the device in physical space.

Fig 2. Wood Cubes in form and material exploration

3.4.2 Cardboard Prototypes for Sizing and Iteration

Following the wooden models, cardboard was used for creating quick and modifiable prototypes. These helped in:

• Estimating internal space requirements for sensors and wiring.

• Experimenting with cube dimensions to ensure comfortable handling.

• Testing various configurations for face interaction and component placement.

Multiple cardboard iterations were made to balance compactness with sufficient internal space for electronics and magnets.

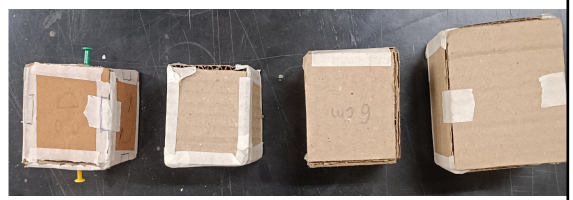

Fig 3. Cardboard Prototyping and variations

3.4.3 Final Sizing and Component Integration

After converging on a viable cube size, the internal dimensions were finalized to accommodate:

- RP2040 M0+ microcontroller
- Hollow rotary encoder
- Tactile switches
- OLED Display Panel
- Magnets for coupling
- Wiring and mounting clearances

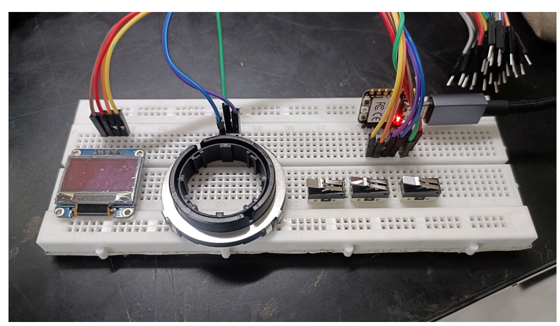

Fig 4. Early Stage Low-fidelity Prototype

This stage ensured that every component could be embedded cleanly while maintaining structural integrity.

3.5 Assembly

To accommodate all components within a compact cube form factor, we used thin copper enameled wire for soldering. This approach allowed us to manage tight internal spacing while maintaining proper electrical insulation. Prior to final assembly, all components were thoroughly tested on a breadboard and through temporary external soldering to validate functionality and ensure correct pin mappings.

Once the design was verified, we 3D-printed the cube enclosure using hard PLA for durability and precise dimensional control. The components were then permanently soldered and fitted inside the printed cube as shown in the **fig.3.5.1**. While the soldering was finalized, we anticipated the need for future changes; hence, the system was designed with flexible backend code to allow updates in pin mappings and functionalities even after physical assembly.

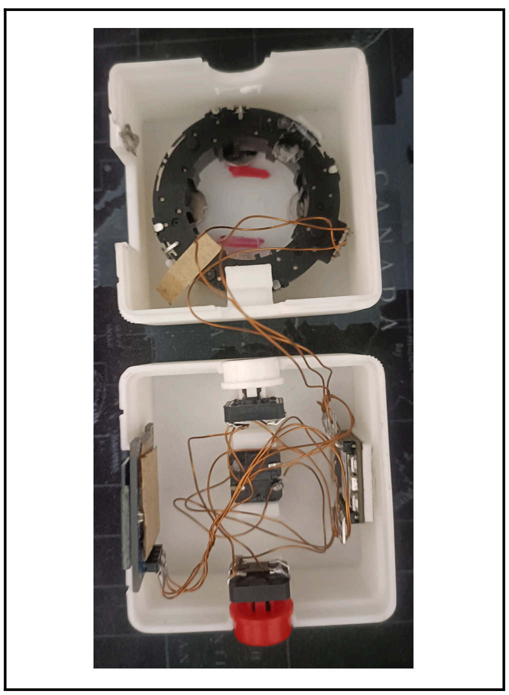

Fig 3.5.1. Internal Assembly & Components

This modular and adaptable assembly method ensured both robustness and maintainability of the final prototype.

4. Final outcome

The current C2C system can integrate a wide variety of functions. The encoder component can be utilized for continuous directional inputs, enabling actions such as zooming in/out, scrolling up/down, and navigating between next/back states. This opens opportunities for its integration in image viewers, document readers, and map applications.

Push Button 1 can be configured to trigger specific functions using simple interaction modes. For instance, a single click could activate a boot loader, select an item, or perform a delete operation, while a long press may be reserved for more advanced or secure features.

Push Button 2 offers scope for more nuanced controls. Single and double-click actions can be mapped to functions such as undo and redo, respectively, providing a streamlined workflow in editing software and productivity tools.

Push Button 3 has the potential to act as a multifunctional control, either by directly triggering functions or by acting as a layer switcher, enabling access to multiple control modes within the same interface. This layered approach significantly expands the system's capabilities and makes it adaptable for complex applications.

Potential use cases for this modular input system include interactive gaming, presentation tools, file management systems, and other human-computer interaction scenarios where compact and versatile input methods are beneficial.

5. Conclusion

The C2C system demonstrates how tangible, cube-based interfaces can enhance digital interaction through physical engagement, modularity, and spatial awareness. Rooted in exploratory prototyping and inspired by taaahe Infinity Cube, the design translates familiar physical manipulation into meaningful digital control. By combining a tech-intensive cube with a low-tech companion, users can perform a variety of tasks—such as navigating files, managing time, or interacting with media—using tactile buttons, rotary inputs, and face-specific functions. The deliberate use of magnets for physical coupling, along with expressive visual feedback via OLED displays, fosters both functional control and playful interaction.

Built around the RP2040 microcontroller and configured as a cross-platform Human Interface Device (HID), C2C operates seamlessly across Windows, macOS, Linux, Android, and iOS. The iterative prototyping process—from wood and cardboard models to fully functional electronic builds—allowed for thoughtful refinement of ergonomics, form factor, and internal layout. By contributing a versatile, intuitive, and embodied interface to the domain of Tangible User Interfaces, C2C reinforces the value of physicality in digital systems and offers a promising direction for future explorations in modular, spatially-aware interaction design.

6. Future work

The C2C system has significant potential for expansion. One promising direction is mapping each face of the low-tech cube to a unique function. When a particular face comes into contact with the high-tech cube, the system can detect and trigger the associated action. This face-based mapping can enable quick and intuitive access to multiple controls using a single physical interface.

Additionally, the integration of multiple low-tech cubes can introduce more complex interactions. For example, different cubes could represent different modes or toolsets, allowing for scalable and modular control schemes. This opens up possibilities for advanced use cases in collaborative environments, gaming, education, and creative applications where multiple users or layered controls are required.

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