TexelBlocks: Dynamic Surfaces for Physical Interactions

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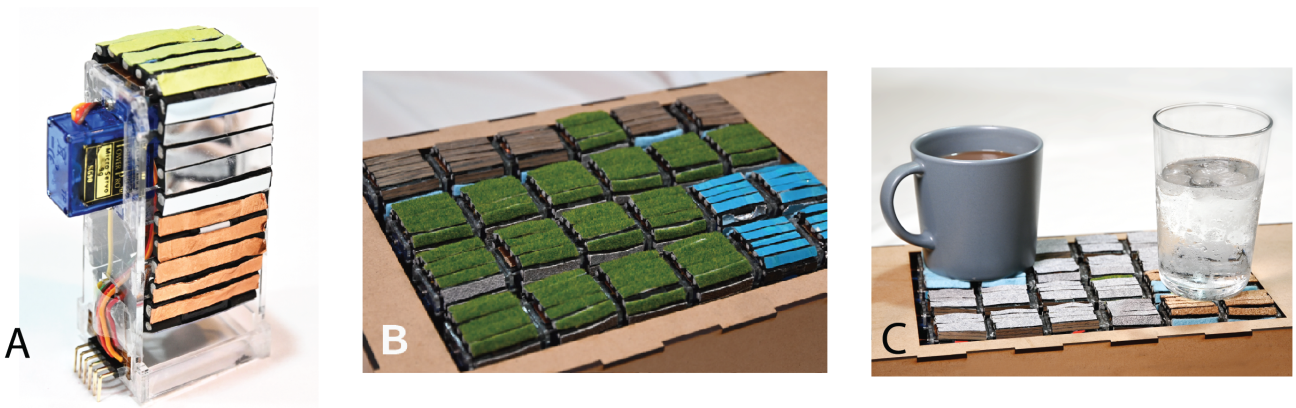

Figure 1: (A) A *TexelBlock* is a modular block that dynamically changes its surface. (B) By concatenating multiple units, it forms dynamic surfaces of various sizes. (C) We demonstrate applications of dynamic surfaces and their physical interactions using our working system. Here, we show one example: a context-aware table that dynamically changes the corresponding areas to absorb heat from a hot coffee mug and moisture from a glass of icy water.

ABSTRACT

We present *TexelBlocks*, modular blocks that dynamically change their surfaces to support rich physical interactions. The core component of each block is a motorized crawler belt with a set of material patches attached to it, allowing each of the *TexelBlocks* to change their surface independently and be concatenated into flat surfaces of various sizes. We implemented a working system that controls 24 *TexelBlocks* to form 6×4 dynamic surfaces. With the working prototype, we developed five applications such as context-aware surface adaptation, real-time tactile feedback, immersive storytelling with dynamic background, real-time embodied platform game, and a surface-changing board game to demonstrate rich physical interactions of dynamic surfaces.

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CCS CONCEPTS

• **Human-centered computing → Interaction devices**; *Interaction paradigms.*

KEYWORDS

physical display, haptic feedback, textures, tangible interaction

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1 INTRODUCTION

Interacting with surfaces is essential in our daily life, from where we walk (floors) to where we work (tables). We manually change surfaces by putting a mat to not only locally change their visual appearance but also provide suitable physical properties for us to interact with. Current technologies such as projectors or head-mounted displays (HMD) enable changing surfaces' visual appearance [7, 9]. There are also researches that revolve around providing haptic feedback on surfaces, such as using real materials [1, 5, 12], or simulating tactile feedback through electrotactile [2, 8] and vibrotactile [3, 11] methods. Moreover, tangible user interface [6] on pin-based shape displays [4, 10] proposes physical interactions with shape and dynamic geometry.

However, there are more physical properties to be interacted with, e.g., magnets providing force from a distance away; metal conducting electricity; mirrors or crystals reflecting light in specific patterns. These physical properties not only directly provide visual or haptic stimuli but also augment interaction modality uniquely.

In this paper, we look into bringing more physical properties to be used on surfaces on the fly to enrich physical interactions. We propose *TexelBlocks*, modular blocks that dynamically change their surfaces (Figure 1A). The key component of each *TexelBlocks* is a crawler belt where a set of material patches are attached. Only one material is presented on the top surface at one time, while the rest of the materials are stored around the block. The whole interactive device consists of multiple *TexelBlocks*, where each of them independently presents their own surface material (Figure 1B). The surfaces are changed dynamically to suit user applications. Figure 1C shows one of our example applications where parts of the surfaces are changed to flannel for a hot coffee mug and cork for a moist water glass.

Our main contribution is a series of physical interactions that utilize various physical properties on dynamic surfaces. We implemented a working system to control 24 *TexelBlocks*, forming a 6×4 dynamic surfaces. To demonstrate the interaction space of dynamic surfaces, we created a boardgame with a dynamic playground to interact with the figure manipulated by the user, generating a more engaging experience. We also implemented a 2D platform game that renders a map with texture and a real-time photo display with tactile feedback to support storytelling or scenario narrating with texture displayed.

2 TEXELBLOCKS

Our primary goal is to enrich physical interactions on surfaces. Since every material has its own physical characteristics, our idea is to design TexelBlocks to switch their materials on the fly to allow more physical properties to be used for interactions. The system diagram is shown in figure 2.

2.1 Hardware Form Factor

Each *TexelBlocks* has a width at 3 cm and a height at 10 cm. Our current prototype uses an Arduino Nano to control a baseboard with 6 blocks in a row. Our final system consists of 4 baseboards that are arranged in parallel. The number of blocks on one baseboard can be made to form different sizes and shapes of dynamic surfaces. The Arduino Nano communicates with applications using the serial port.

Each TexelBlock consists of a belt with material patches, an RGB sensor (TCS34725), gears, and a 360 servo motor (SG90), as shown in figure 3. The acrylic shell of a TexelBlock is 2-mm thick. The top surface of the block is set as a square of 3×3 cm^2. We used color labels on the back of the crawler belt and the RGB sensor to identify and position materials. The belt wraps around the block and is driven by the servo motor inside. The motor is controlled using PWM via the Arduino Nano board. A set of gears are used

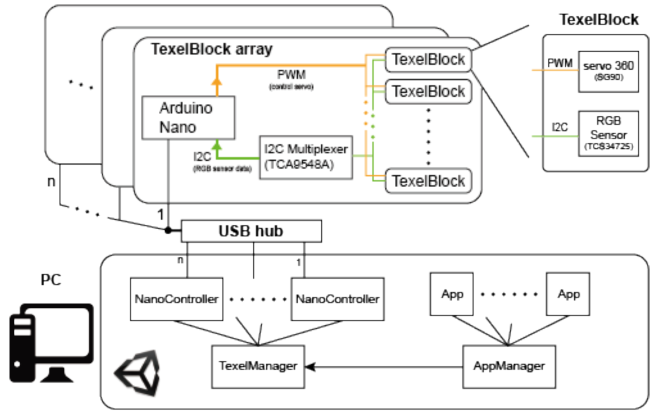

Figure 2: This diagram shows the complete architecture of our TexelBlocks system including the hardware wiring and the software system.

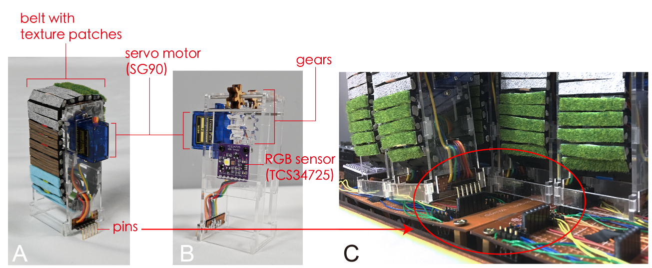

Figure 3: (A) A TexelBlock is modular block with a belt that has 6 types of material covering its surface. (B) A TexelBlock without a belt outside to show the inner structure. (C) The baseboard of dynamic display is readily wired. We can assert pins of each TexelBlock into the board.

for transmission. We used a multiplexer (TCA9548A) to integrate the sensor data of each TexelBlock into the SDA pin of the Arduino Nano board. To optimize the performance, the rotating direction is determined using the shortest distance from the current material to the target material. All of the wires are sorted to the pins on the bottom of the block to allow it to be attached to a baseboard easily. The baseboard has holes for the pins and is readily wired to Arduino boards and power sources.

2.2 Software Control System

We built a software system using Unity. The system has a GUI for users to visualize and control the TexelBlocks and provides APIs that enables designers and developers to implement new applications.

2.2.1 Graphical User Interface. As shown in figure 4, the size of *Texture Canvas* is set manually by the number of columns and rows on the bottom left of the interface. The user assigns materials to each color label in *Texture Palette*. The user drag a desired material from the top to the *Texture Canvas* and the TexelBlocks will change its surface accordingly.

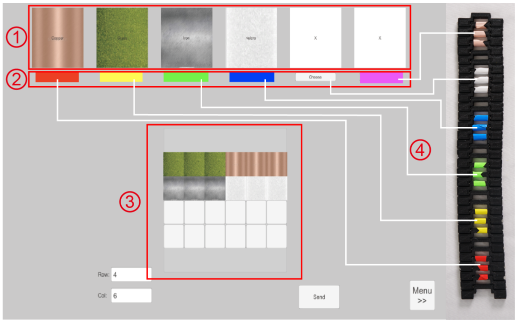

Figure 4: The GUI for our dynamic display. (1) *Texture palette* shows materials on the crawler belt. (2) The color mapped to the crawler belt. (3) *Texture canvas* indicates which material of the *TexelBlocks* arrays are currently showing. (4) The palettes are mapped to the color labels behind the belt.

2.2.2 API. To support different applications, we provide Unity API. The architecture is shown in figure 2 The *AppManager* has two main functions:

- Initialize: set up mapping from *Texture Palette* to the crawler belt.
- SetTexture: determine the material on each block's surface to match the *Texture Canvas*.

The *TexelManager* controls the whole dynamic surface. It receives function calls from *AppManager*, and distributes the instructions to *NanoControllers*. Each *NanoController* controls an Arduino Nano board, which also refers to a TexelBlocks array.

3 APPLICATION

We explore physical interactions of dynamic surfaces by developing several applications, such as a context-aware table, providing real-time tactile feedback of photos, immersive storytelling with dynamic background, real-time embodied platform game, and a self-designed surface-changing board game.

3.1 Dynamic Table Surface for Daily Use

We introduce the concept of dynamically changing the table surfaces' material to suit daily uses (Figure 1C). When we place a hot beverage on the table, wooden or silicon-made heatproof mat is often used; when we place icy beverage on the table, diatomite can help keep the table surface dry; when we slice paper with a utility knife, we place PVC cutting maps on the table; when we want to put little animal figures on the table, a rocky field or grassland can be desirable. With tangible material-displaying bits, this concept of dynamic table surface has taken a step toward reality. This application is a mock-up for a context-aware surface, where the controlling of the surface is manipulated behind scene for now.

3.2 Touchable Photo Frame

Through computer vision, we analyze the texture presented in an image and display them on *TexelBlocks* to provide tactile information, letting visually impaired users perceive the scenery or browse through photos with an array of *TexelBlocks*. Currently we picked a few pictures that fits the current texture patches, and used OpenCV in Python to slice the image and categorize the pieces into corresponding textures and display it on our device.

3.3 Supporting storytelling with texture

In the field of education, learning effects are proven to be enhanced by multi-sensory feedbacks. By using an array of *TexelBlocks*, any storybook can be extended with tactile feedback. With parents or teachers setting the scene ahead, textures change along with the narrated contents. The bigger the array of *TexelBlocks* is, the more user can interact with at the same time (Figure 5A). As it renders the story's scene on it, kids can touch it while listening to the story, just like having a miniature world from the story's world right in front of them. They can embody themselves into the story scene and even take toy figures and tell their own story on this miniature stage. This usage can also be applied in videos such as cartoons.

3.4 Texture Mini-map

We implemented an 8-bit RPG game enhanced with physical interactions. There are trees, rocky roads, grass, wood fences, water, and treasure cases(represented by aluminum foil) in the game (Figure 5C). On the 6×4 array of *TexelBlocks*, the center's slightly right-top block represents the player's position. The player navigates around by stroking the surface to perceive the surroundings, then double-tap on a particular *TexelBlocks* to indicate the block they would like to step onto. The region displayed on the array will shift to where the player's destination is in the center. We implemented touch sensors beneath the crawler belt to acquire the users' movement. While the crawler belt's rotation sometimes interferes with the touch sensor, we currently identify gestures instead of touches. The sensing technique could be further improved by pressure sensor.

We envision that by combining more blocks into a bigger array, more users can join the game and broaden the interactivity. This application not only serves as a new gaming form, but it can also support visually impaired users in gaming.

3.5 A Boardgame with Physical Properties

To realize the idea of putting more physical properties into designing interactions, we created a boardgame based on Monopoly. This boardgame has two primary features.

3.5.1 Special Objects.

- *Avatars.* The avatars that represent the players in the game are specially designed to interact with the gameboard (Figure 6). The anterior part of it is a space that can hold liquid. Every figure is filled with a liquid of different pH values. The players mark their territory by dropping the liquid from the figure's peak onto a universal test paper (Figure 6D). The figure's eyes are LED in which the switch is an open circuit at the bottom. When the figure lands on a material that conducts electricity, the figure's eyes will light up (Figure 6E). Lastly, there are magnets embedded in the bottom of the figure.
- *Health bar.* Other than the figure, each player has a bar that indicates the player's health status in the game (Figure 6B). It

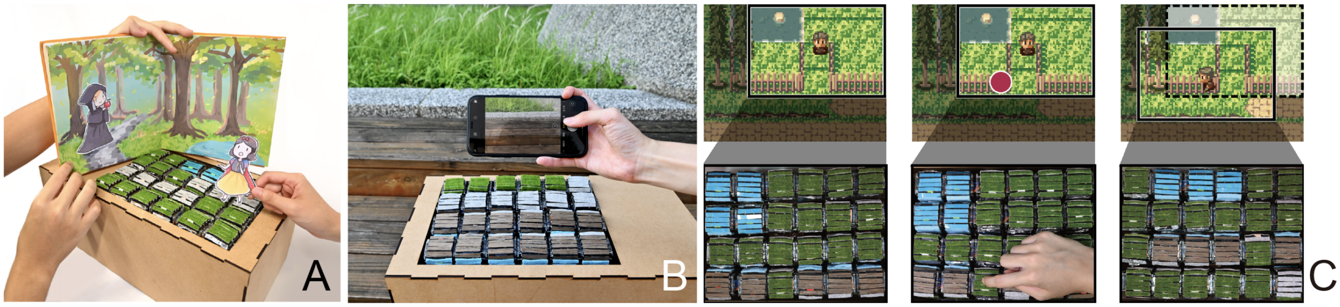

Figure 5: (A) Storytelling with dynamic surfaces as the extension of the storybook. (B) Rendering photos with materials. (C) Gaming with the virtual environment rendered on the surface. The upper part of the picture is the actual gaming situation. The lower part is what the users see and interact with.

is a pillar-shaped object made with low-density polyurethane foam. It shortens when users grind them on sandpapers (Figure 6C).

3.5.2 Dynamic Gameboard. In this game, the playground changes its arrangement dynamically. Each time a player walks, the gameboard changes its surface, indicating new random events for the next user. Events are triggered or presented with interactions using physical properties. We chose six specific materials that each provides certain interaction and indicates particular events:

- *Magnet* - The magnet attached to the *TexelBlocks* could be the same or opposite polar from the ones attached to the gaming avatar. When the player passes, it may push or pull against the avatar, meaning that the avatar is forced to go on or forced to stay.
- *Copper foil* - When the player's avatar steps onto the copper foil, the open circuit on its bottom gets connected, thus light up the avatar's eyes. Indicating that the player has triggered a chance or fortune event.
- *Mirror* - On the trigger of the chance and fortune event, random blocks of the gameboard switch into mirror material. The player holds a laser pen that has a limited rotating angle and shoots the laser onto one of the mirrors from one side of the gameboard. The laser beam will reflect onto an event printed on a board that stands on the other side of the gameboard.
- *Stringed beads* - Stringed beads are attached to *TexelBlocks* by its string, preserving its freedom to spin. More than one block might switch into bead material simultaneously, allowing the user to flick the avatar and roll along the beads. This provides a method for moving forward other than merely rolling dice.
- *Universal test paper* - Universal test papers reacts to both acid and alkaline and has 14 colors for pH value from 1-14. The avatars contain different liquids; the red one contains citric acid (pH3.0, reddish-orange); the yellow one contains vinegar (diluted to pH6.0, yellow); the blue one contains baking soda (pH9.0, blue). The players mark their territory by dropping liquid onto these test papers.
- *Sandpaper* - Using the health bar mentioned above, every time the player unluckily steps onto a block with sandpaper, they lose their health point by grinding their health bar.

We invited 12 users and separated them into 4 groups to experience the game and gathered feedback about the inspiration they get from this device. Overall, users reported it interesting and challenging. They came up with various ideas related to both physical interaction and the concept of dynamic surface.

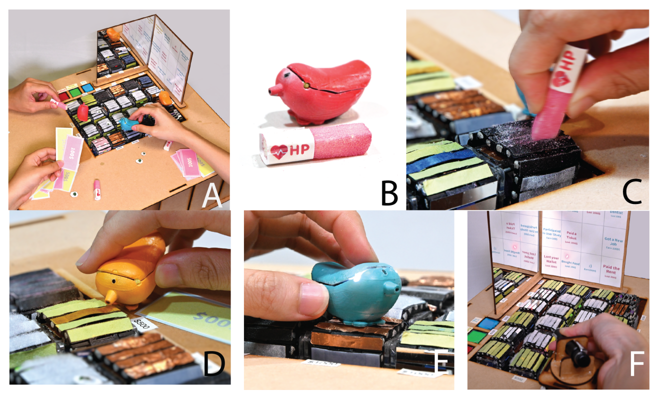

Figure 6: (A) Overall view of the gameboard. (B) The bird-like figure on the top is one of the users' avatars. The one on the bottom is the HP bar. (C) the users have to grind their HP bar whenever they step on a sandpaper block. (D) The user marks their territory by dripping liquid onto the universal test paper. (E) Whenever a user steps onto copper, the avatar's eyes lid up. And the user gets to (F) use the laser pen to point onto the reflect the light onto the desired event.

4 LIMITATIONS AND FUTURE WORK

There are several limitations in our current prototype that could be overcome. First of all, the crawler belt is currently 3D printed. Other fabrication techniques such as extrusion molding may better support mass production. Fabricating more crawler belts could enable more types of texture and benefit applications such as the touchable photo frame. Moreover, the motor in each block's center could be a smaller and faster one to enhance resolution and performance.

Lastly, since each *TexelBlocks* is controlled independently, more applications can be carried out on various array sizes of *TexelBlocks*. The control board for the blocks can be changed to a larger size to support larger design space or even modify the whole device to make each *TexelBlocks* be controlled remotely.

5 CONCLUSION

We have presented TexelBlocks, dynamic material displaying bits that can show the user's demanded material on the surface and can be concatenated into various sizes of arrays. We implemented a working system where users interact with TexelBlocks and control them with a GUI. We combined 24 blocks into an interaction device and demonstrated five applications: context-aware table surface, tactile information derived from the virtual or physical world, story narration with a miniatures stage, enabling multisensory learning, video games played by dynamically rendering the map with materials, and a boardgame that lets us explore the unique physical properties of materials.

The concept of inter-object interaction with various physical properties more than tactile and visual enriches interaction design and expands the possibility of tangible bits.

We envision the future where interactions are involved on dynamical surfaces; interaction devices can simultaneously provide tactile feedback and material's spectacular physical properties.

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