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Article

Design and Practice of STEAM Interactive LED-Cube Teaching Aids

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Abstract: STEAM education integrates Science, Technology, Engineering, Arts, and Mathematics into interdisciplinary learning. The development of interactive media design requires proficiency in programming, art, emerging technologies, and artistic concepts across such disciplines. However, existing curriculum frameworks frequently face challenges in adequately instructing and integrating skills that are relevant to interactive media development including programming, 3D modeling, animation, and presentation. Due to limited knowledge, abilities, and time, students cannot experiment with different display methods for showcasing their works. Despite recognizing the importance of cross-disciplinary integration, such limits in resources and abilities reduce their willingness to put them into practice. Therefore, we provide a toolkit that allows students to learn and simplify the integration process of interactive media development. They are used to encourage students to try cross-domain collaborative creation and implement the STEAM education. We designed Arduino modules integrated with Unity to implement a real-time display LED cube system (RLDS). Bluetooth or WiFi technology is utilized to achieve the scalability of the LED cube modules. A communication package transmits interactive data between the 3D content system and the Arduino-based LED cube display system. Through the use of RLDS, students can learn various integrated applications of digital media technologies, which is beneficial for their future interactive media creations.

Keywords: STEAM, LED Cube, Arduino, Expandability, Interactive Design

1. Introduction

Core competencies in higher education are a pressing and prevalent issue, driven by concerns of students, governments, and employers regarding the quality of outcomes. Universities must design a curriculum to develop students' knowledge and core competencies for skills of communication, information and technology, numeracy, learning, problem-solving, and collaboration (Hadiyanto, 2010). Digital media design demands developing innovative and creative interactive media by integrating various technical elements and applying knowledge in diverse domains. Related curriculum is necessary to foster the personal growth of individuals with core competencies, rather than being narrowly focused on a single discipline of knowledge.

Don (2010) stressed that traditional skills such as sketching, modeling, detailing, or rendering have limited applications in addressing emerging design domains. He argued that modern design demands a broader understanding encompassing interdisciplinary knowledge, including engineering and scientific fields. Such interdisciplinary education helps designers better comprehend and address complex problems, leading to the creation of products with greater value and significance. Furthermore, He underscored the importance of interdisciplinary collaboration, stating that specialization in a single domain is no longer sufficient. Thus, designers must engage in collaboration with professionals from diverse fields to address multifaceted and multidimensional challenges. This interdisciplinary teamwork not only enriches the design process but also plays a crucial role in generating more comprehensive and impactful solutions. Digital media design inherently operates at the intersection of technology and design, making it an interdisciplinary field. A current focus in higher education is how to enhance students' practical competencies and exploratory abilities, ignite their motivation to learn, promote collaborative efforts, and foster a driving force for students to boldly seek knowledge and integrate interdisciplinary thinking.

Considering such educational focuses, we have developed dynamically showcasing 3D digital toolkits using the widely-used Arduino-based LED cube, a modular and expandable methodology, and the popular game engine for interface design. Within digital multimedia design courses in higher education, the toolkits were developed to naturally introduce students to the integration and application of interdisciplinary technology, encouraging them to explore diverse presentation methods for future digital endeavors.

2. Related Works

In the digital era, digital and cross-disciplinary design education has become a significant trend in current higher education. Digital media design is interdisciplinary as it needs to integrate the fields of technology, engineering, and visual design. Due to the high technical threshold required for creating with information technology, students often abandon their original intentions and ideal interactive digital media projects at the conceptualization stage. In the emerging age of technological applications, products lacking interactivity face challenges in effectively communicating their usability and experiential value. To expand students' viewpoints and encourage their proactive engagement, we investigated how interactive content development skills have been used. The results were used to create innovative teaching toolkits and activities that not only ignite students' enthusiasm for learning but also promote collaborative teamwork.

2.1. Importance of STEAM

STEM education, an interdisciplinary curriculum merging Science, Technology, Engineering, and Mathematics, emphasizes problem-solving through design exploration, leveraging technological skills and scientific thinking. Its educational objectives span competencies and skills across various domains, including science, technology, engineering, and mathematics. Becker and Park (2011) suggested that interdisciplinary STEM education, which combines various subjects, is more effective in stimulating students' enthusiasm for learning compared to singular approaches (such as focusing solely on mathematics) or other interdisciplinary subjects (such as Mathematics, Science, and Technology (MST)). STEM development encompasses interdisciplinary integration, technological integration, hands-on learning, innovation and entrepreneurship, global collaboration, and social responsibility. Additionally, the integration of artistic aesthetics into STEM education results in STEAM, further enhancing capabilities. In short, STEAM education cultivates a workforce that is well-rounded, adaptable, and innovative, poised to tackle the complex challenges of the 21st century.

2.2. Arduino for Education

Arduino is an open-source electronics platform that offers a versatile and user-friendly environment for crafting interactive projects. Comprising both hardware and software components, it facilitates the prototyping and development of a broad spectrum of electronic devices, appealing to hobbyists, students, and professionals alike (Poudyal et al., 2019). The success of the Arduino platform is attributed to its key features, including its open-source nature, adaptability, simplicity of technology, accessibility to sensors and actuators, and constant software updates (Zlatanov, 2015). The open-source nature of Arduino, coupled with its large community, fosters continuous growth and evolution, positioning it as a valuable platform for individuals at all skill levels. Furthermore, it reflects the future trends in hardware development. Jiuqiang (2015) advocates for utilizing the Arduino platform as a teaching tool for design practices. This platform seamlessly integrates software and hardware, offering convenience for both teaching and designing intelligent product prototypes.

Arduino in education has its significance as a versatile tool for teaching various subjects, particularly in STEM education. Many educators have highlighted Arduino's accessibility, affordability, and ease of use, making it suitable for learners of all ages and backgrounds. For instance, Al-Masri et al. (2020) incorporated hardware prototyping platforms in academic settings and advocated for additional research to explore their effects on student learning. Danković et al. (2023) stated that students who gain practical experience in high school exhibit higher levels of self-confidence and achieve better scores in university compared to those without such experience. Universities need to take proactive steps to enhance collaborations with high schools and professional societies to foster these connections.

Arduino is used in formal education curricula at different levels, from elementary schools to universities. Educators have developed innovative teaching materials, lesson plans, and projects using Arduino to engage students in hands-on learning experiences. In these activities, problem-solving, critical thinking, and creativity are emphasized, aligning with modern educational frameworks such as project-based learning and inquiry-based learning. Additionally, there has been a growing emphasis on interdisciplinary applications of Arduino in traditional STEM subjects as well as in art, design, and humanities. This interdisciplinary approach fosters creativity and cross-disciplinary thinking among students.

2.3. LED Cube Products

LED cube products, consisting of three-dimensional arrays of LEDs arranged in a cube shape, are popular among hobbyists, makers, and enthusiasts for their aesthetic appeal and potential for interactive projects. LED cube products are a versatile platform for experimentation, learning, and creative expression, making them popular in various fields such as art, education, and technology. They provide an engaging way to explore concepts in electronics, programming, and visual design while also serving as eye-catching decorations or promotional displays. In an 8 × 8 × 8 LED Cube with the Arduino, eight 74HC595 ICs were used to control 64 anodes (positive poles, depicted by red lines), and one 74HC595 IC was used to manage 8 layers of cathodes (negative poles, represented by blue lines). Its simplified circuit design emphasized expandability. It also highlighted the widespread adoption of Arduino modules in numerous interactive designs and the innovation of new applications. It is significant to simplify the circuit for scalability. The entire system requires only three pins from an Arduino for control, significantly reducing the output pins needed and completing the circuit design for the LED cube as shown in Fig.1. This circuit design of the LED cube prioritized the efficiency and ease of control in design (Derek, 2020). However, while these LED modules have expandability in terms of hardware modules, they lack flexibility in content development for the display. Specifically, one needs to reload new programs to make them operational, making it less suitable for content developers looking for real-time interactive displays. A new LED cube display system is proposed to enhance the system's scalability through a specified content transmission protocol.

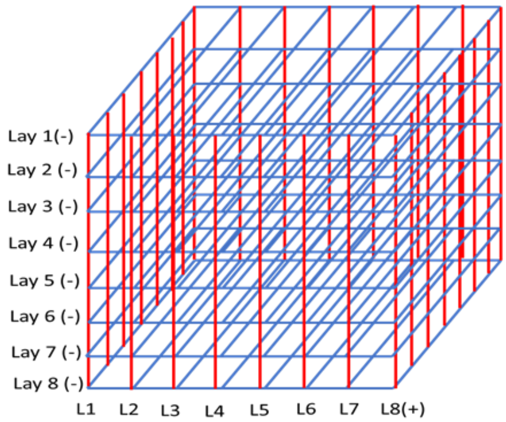


Fig. 1. Circuit design of 8 × 8 × 8 LED cube.

2.4. Unity Game Engine

Unity Game Engine, first released by Unity Technologies in 2005, is a widely-used and adaptable game development engine that empowers developers to craft various types of games, including 2D, 3D, augmented reality (AR), and virtual reality (VR) experiences, simulations, and interactive content. Encompassing fundamental capabilities, the Unity game engine includes features such as Cross-Platform Development, Graphics and Rendering, Physics Engine, C# Scripting, Networking, Collaboration, Asset Store, and more.

In this study, we used C# within the Unity game engine, as well as network connectivity, to convey physical trigger information from the game scene to the LED cube module. The expandable cube allows for the presentation of game content. Throughout the design process, we considered the system's flexibility and scalability.

3. System Design of Real-time Display LED Cube System (RLDS)

3.1 Overview of Expandable RLDS

The expandable RLDS consists of three main components: 3D Content Design, Data Transform, and Display (Fig. 2).

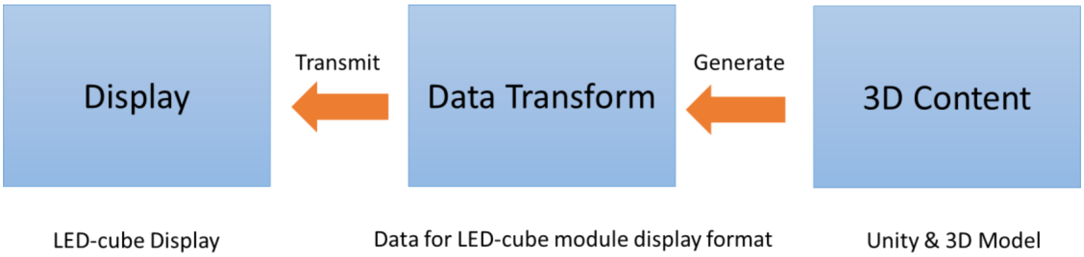


Fig. 2. Diagram of RLDS.

1. 3D Content Design: Utilizing the Unity 3D engine as the primary design platform to create the content. Content developers can place their 3D objects or animations into the scene which are processed by the system to generate display data for transmission.
2. Data Transform: Transforming information from 3D content, utilizing the simulated physical characteristics of the game engine, and combining it with the content the designer intends to display. This conversion process results in a format recognizable by the display module.
3. Display: Showcasing the content conveyed by the content management system. The LED-cube module serves as the targeted display platform for this system.

In the market, there are already many Arduino-based LED-cube modules. We used Arduino's integrated development environment (IDE) and the Unity game engine to create various applications, offering a new interactive display mode distinct from conventional screen-based content presentation.

3.2 RLDS

RLDS allows for synchronizing the transmission of trigger data to all Arduino-based LED cube displays and enabling flexible combinations. This is pivotal for investigation and exploration. The system integration is depicted in Fig. 3. The data transmitter employs network transmission technologies, integrating the developed communication package into the game scene. It transmits data through a predefined consistent data format via the network. Subsequently, the collected content information is dispatched to each LED cube display module for processing and analysis. Following data processing, each module displays the content on its respective LED cube, thereby realizing the expandability of the RLDS system.

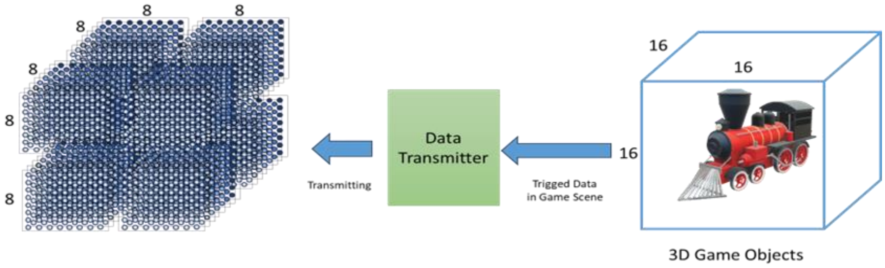


Fig. 3. System overview of expandable RLDS system.

3.3 Initialization and Executions

The scenario of initialization and communication between LED Cubes and the RLDS content is presented in Fig. 5. The transmission data format is shown in Fig. 4. The LED cube and the RLDS communicate through various modes for the interaction and synchronization of visual content. Communication modes include wired or wireless connections, depending on the specific implementation. Typical communication protocols such as USB, Bluetooth, Wi-Fi, or others can be used according to the system's requirements. The RLDS content manager serves as the central hub for transmitting data to individual LED cubes, ensuring coordinated and synchronized displays across the entire array.

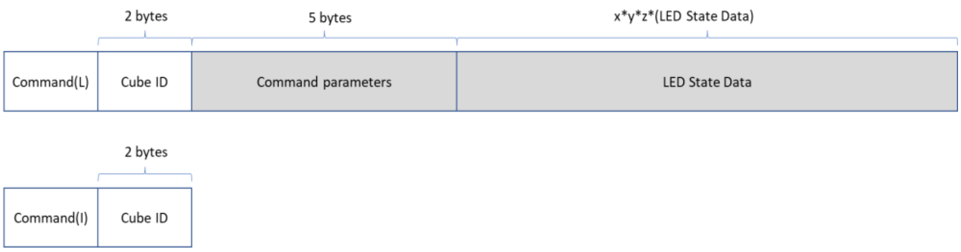


Fig. 4. Data transmission format of RLDS.

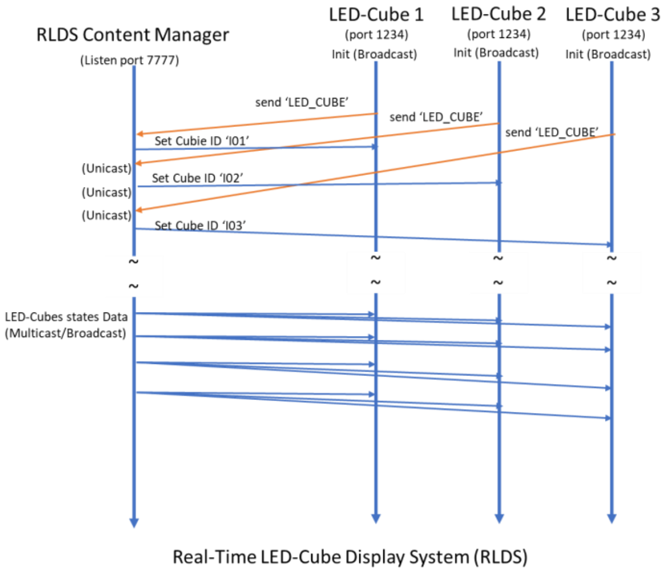


Fig. 5. Communication scenario between led cubes and RLDS content manager.

4. Results

We tested a prototype of an expandable RLDS. Using wireless transmission technology, content data for display was sent to the LED cube display modules for presentation by the content manager. The implementation results, including LED cube initialization and a demonstration case, are detailed as follows.

4.1. LED Cube IP Setting

In the event of a failure to connect to the local access point (AP), the LED cube automatically switches to AP mode with the default IP set to 192.168.4.1. A browser can be used to configure the network settings for the new access point (AP-1). The LED cube connects to the AP-1 to obtain an IP address from the DHCP server in the access point. If necessary, the player can modify the LED cube's network settings using the new IP address via a web browser. At the LED Cube's IP Setting process, we employed Arduino resources from the WiFi Configuration Manager with a web configuration portal designed for Espressif ESPx boards by Tzapu (2024) to develop a system that offers users the flexibility to modify AP and IP address settings, thereby enhancing the convenience of operating the LED cube. Figure 6 illustrates the process of setting up the AP and IP address.

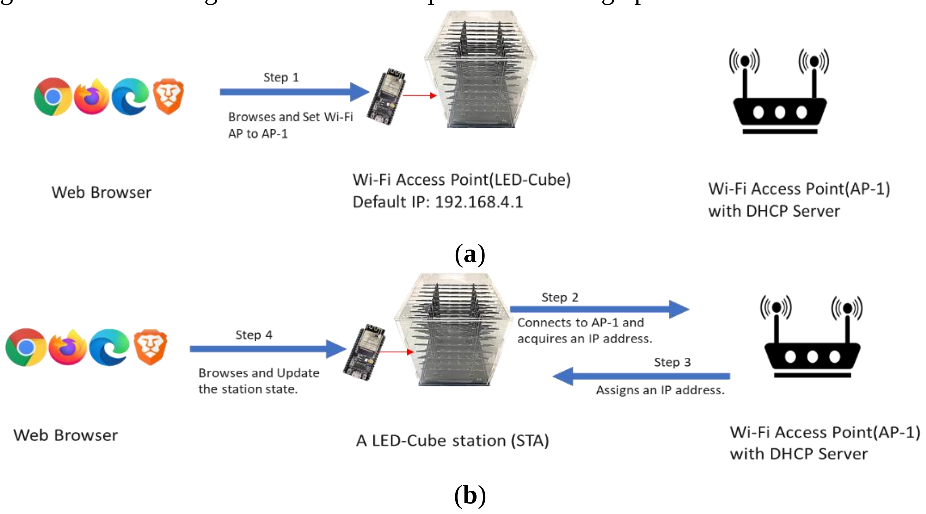


Fig. 6. Process of set-up of AP and IP addresses.

4.2. LED Cube ID Assignment

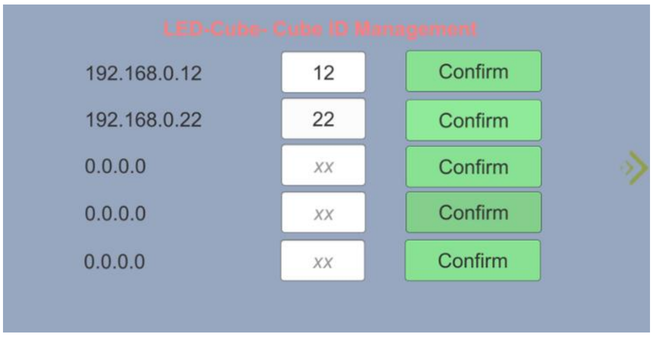


Fig. 7. ID assignment in RLDS.

In the ID assignment process, each LED cube in the same network segment proactively broadcasts to acquire their cube ID requirements. Subsequently, the user assigns and confirms their unique IDs in the RLDS system and assigns different IDs to the active LED cube with regular IP addresses. The configuration interface of the RLDS system is shown in Fig. 7.

4.3. 3D Moving Object Display

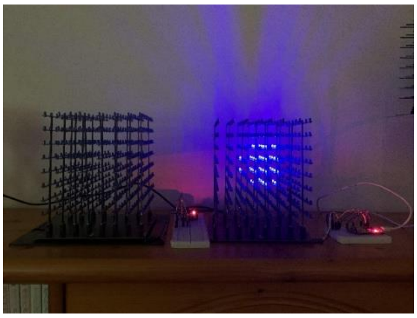
Figures 7−10 show a simple demonstration of ID initialization, cube arrangement, and executions of the RLDS system with two active LED cubes.

(**a**) (**b**)

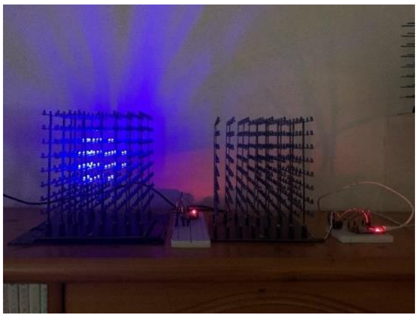
Fig. 8. LED cubes' ID assignment and arrangement. (**a**) 3D scene with two active LED cubes. (ID! = "00"); (**b**) Two active LED cubes.

(**a**) (**b**)

Fig. 9. A moving 3D blue ball crosses from (**a**) LED-Cube with ID 22 to (**b**) LED-Cube with ID 12 in the RLDS Content Display System.



(**a**)



(**b**)

Fig. 10. LED cubes present interactive content where the blue lights moves from (**a**) the right side to (**b**) the left side, corresponding to the 3D ball track in RLDS.

5. Conclusions and Future Works

The cube and RLDS effectively demonstrated 3D content utilizing wireless transmission technology. The data transmission format was accurately defined showing the potential for its applications and enhancements. Managed by the content manager, RLDS proved to be innovative and interactive in applications. The detailed implementation process such as LED cube initialization and a demonstration case underscores the potential for diverse applications. Further refinement and optimization of the RLDS are necessary to advance the interactive display technology.

Using the developed tool, students can comprehend various integrated applications of interactive media technologies, including wireless data transmission, Arduino applications, and 3D modeling. They also learn how to apply these technological elements in their future creative endeavors. For further advancement, the following is needed.

1. Usability enhancements to refine the system's user interface and address any existing usability challenges to ensure an optimized user experience;
2. User Feedback incorporation to assess user learning outcomes and enhance system functionality according to user requirements;
3. Cross-disciplinary applications to explore potential applications in art installations, data visualization, or interactive advertising;
4. Educational integration to effectively integrate the system into information technology education in primary and secondary schools.

We plan to enhance the RLDS system for various applications by refining and integrating it with advancements in 3D art and interactive design for interdisciplinary learning. The developed RLDS, with its content technology encompassing communication, engineering, and art, can assist in integrating emerging technologies into STEAM education through instructional design.

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Data Availability Statement: The data of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

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