Smart Table

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Abstract—This paper presents the realization of a unique digital signage display with multiple integrated functions. As such this is a combination of bluetooth, embedded systems, and RGB LEDs to create a one-off design. The end-user of this project can use a simple bluetooth connection to control all the available functions of the display. This project was built with the idea of unique, viable, and interesting in mind.

Index Terms—Bluetooth, Displays, Microcontrollers, Coprocessors, Pulse width modulation.

1 Introduction

This project is to design a table that would have a moderately sized matrix of individual cells on the top that would act as pixels. Each so called cell would consist of an RGB Led to produce any given color value which would likely be achieved through pulse width modification. Each cell would also have a LED driver that would act as a slave to a main microprocessor on another main board. Located in the specifications below is a detailed list of functionality to be included in the project. Timekeeping, various idling modes,and playing games such as Snake.

This device will not necessarily be designed with inherent market value in mind. The device will have relatively cheap production cost, however the primary motivation for designing the product is simply as an academic exercise in an effort to improve the members understanding of integration across various subsystem. This is a proof of concept design that has potential to extend into the market in future renovations, if a highly practical concept is prepared.

One form of interactions will be through an application that will be developed to stream data to the table and provide an interactive interface for the user in addition to physical tactile feedback in the form of buttons embedded on the table itself. This will provide a higher entertainment value for the end user, as such is something that is not directly quantifiable.

The device will be supplied from mains supply, plugging directly into the wall. This voltage will be transformed down, then rectified and regulated to acceptable values for the processing units and RGB light generating units. The physical space of the power supply on the board will be at a relative minimum, with heat sinking of the parts, if required, taking up an appreciable fraction of space.

The total size of the table will be relatively large, based solely on the scope of the display. As the display is consisting of 512 individual LEDs the final design of this project ended up being the size of a coffee table with an array of 32 * 16 LEDs.

2 System Components

2.1 Microcontroller

The microcontroller is arguably the most important part of the smart table. As this component will have the highest number of tasks of the entire electronic system of the table and process the most code. As the main processor of the smart table, it will directly control the LED matrix as well as interface with the Bluetooth module to receive various remote commands from the user. For this project, the TMS320F28379D was selected as it offered a large amount of power for a microcontroller while staying within the TI family. As such this microcontroller offers Two TMS320C28x 32-Bit CPUs, up to 200 MHz per core, full floating point support with various accelerators, and more than enough physical pins for controlling the devices and additionally leaving the option for future expansion open.

2.2 Bluetooth

The Bluetooth module is a critical component that will enable access to the device's core features using wireless communications. With a Bluetooth module, the smart table will be compatible with a staggering number of consumer devices, and will be able to receive commands remotely from the user. The Bluetooth module will essential act as the interpreter between the microcontroller and the user. For this project the RN-42 module was chosen, which supports Bluetooth 2.1. It is important to note that the current draw and power efficiency characteristics were not strong considerations when selecting this module, because the smart table will be plugged directly into the mains electricity and will not need the same level of power optimization that is needed for portable devices. Rather, emphasis was placedon a device that was wide compatibility with existing products, which Bluetooth 2.1 manages to do successfully. Newer standards such as Bluetooth 4.0+ only work with the latest generation of smart devices, which could negatively impact the accessibility of the smart table to its audience. Additionally this module offers relatively easy integration into projects and is well documented.

2.3 RGB LEDs

The LED matrix is the central feature of the smart table and will serve as the main display. It is comprised of 512 RGB LED chips connected in serial. The LED matrix will be arranged in a standard 2:1 ratio display for integration into the table. Chosen for this project the WD2812 based LEDs as they offer an acceptable engineering to monetary trade-off. As such the LEDs come on strips for a relatively low cost but as a trade-off they require more effort for communications control. This trade-off will be further explained in the software design section.

2.4 Power Supply

The power supply was decided to be outsourced due to the requirements posed by the number of LEDs being used. As such, the sheer power draw and fluctuating draw required the project to buy an off the shelf power supply instead of risking any sort of home-brew device.

3 Hardware Design

3.1 Hardware Block Diagram

The hardware block diagram in 1 is a top-level depiction of how devices withing the smart table will interact with each other. The table will run off of 120VAC mains electricity, which will be passed through a transformer. and stepped down to 24VAC. An AC to DC rectifier will convert the voltage to DC at which point it will be stepped down to 12V with a regulator. The LED matrix will receive 5V input using a 5V regulator, and the Bluetooth module and main microprocessor will utilize 3.3V using a regulator. Bluetooth communications will be transmitted to the Bluetooth module from an external device. The Bluetooth module will relay this information to the microprocessor through a UART interface, and the microprocessor will in turn directly manipulate the LED matrix.

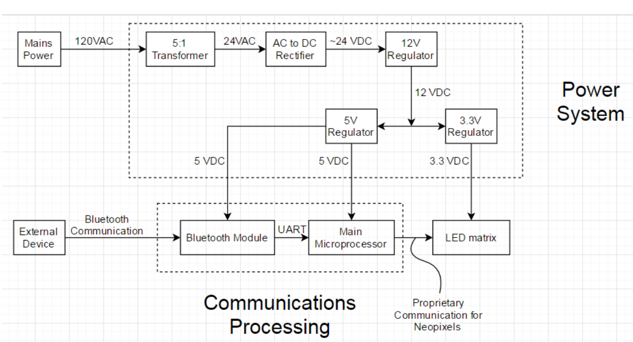


Fig. 1: Hardware Block Diagram

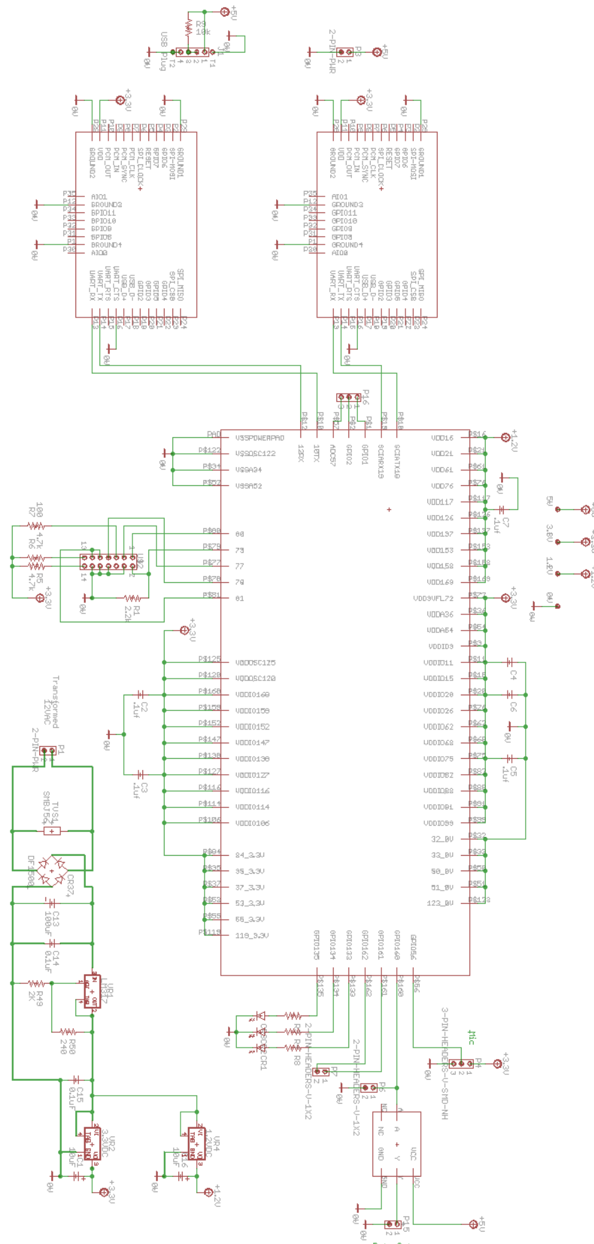


Fig. 2: Hardware Schematic

3.2 Power

The system draws power from the 120VAC mains power that has been transformed down at a a ratio of 10:1. This 12VAC input to the system is protected by a transient voltage suppressor in order to protect the sensitive devices downstream such as the Bluetooth modules and the microcontroller. This signal is then rectified by a full bridge rectifier to produce a DC signal, then regulated down to produce 2 of the three necessary voltages. A

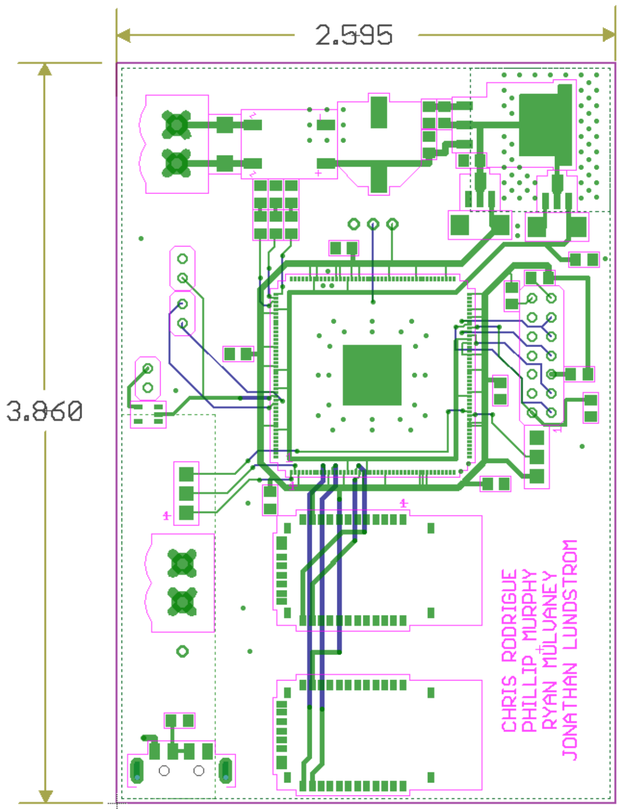


Fig. 3: Board Layout

major concern of this design was the heat output of the 6VDC linear regulator, which has been solved by proper heat sinking. Initially, the design called for a 24VDC signal to be regulated down to 6VDC. However, this caused the linear regulator to overheat due to the large voltage step down required. The 6VDC output from this linear regulator is then directly supplied to the inputs of 2 more linear regulators, 1.2VDC and 3.3VDC. The 1.2VDC produced is used explicitly by the microcontroller, and the 3.3VDC rail is responsible for supplying the microcontroller GPIO pins and powering the Bluetooth modules. The 12VAC input is not responsible for the 5VDC power rail, this is supplied externally by the auxiliary 5VDC supply that is also responsible for the LED matrix. The 5VDC signal is also responsible for the USB charging on board, and it is also important to tie the 5VDC reference to the board reference to ensure that the level conversion on the data end of the system can occur properly. This will be discussed in the next section below. Various test points exist on the board in order to ensure proper voltage levels are being maintained by the system. The entire Wireless communication Bluetooth 2.1 is the communication protocol implemented by this project. There are two Bluetooth modules on the board in order to support multiplayer interaction to the table through multiple separate Bluetooth enabled devices. These lines directly connect to the microcontroller and act as the primary input to the system. On the board, there is a keepout area to keep the ground plane

3.3 General Layout

The board is broken into logical blocks on the board for ease of design and troubleshooting. The power supply for the microcontroller and the Bluetooth modules is located on the top border of the PCB. There are short, thick traces in this area to ensure that there is as little resistance introduced as possible. The input header is located in the very top left, which allows 12VAC to enter the board and supply the regulators. The output for the final two power rails that feed the rest of the board are located directly below the regulator heat sink found in the top right corner. The microprocessor is located in the center of the board with its own heat sink. This particular microprocessor requires a 1.2V source and a 3.3V source in order to operate, and as such it was decided to have the power traces follow the microprocessor pins all the way around, with the 3.3V trace on the outside and the 1.2V trace on the inside. This wrap around method was chosen because several pins on the microprocessor require power. There is however, one main ground for the board, located on the pad directly in the center. There is also a header for programming the board located directly to the right of the device. This allows the device to be reprogrammed on the fly through JTAG. At the bottom center and bottom right of the board is the area for Bluetooth interaction with the microcontroller. The two separate devices allow for ease of multiplayer integration for various applications, mostly games. There is a keep out area in the bottom right hand corner of the board in order to allow the two Bluetooth modules to transmit through the board, as the 1 oz copper pour on both sides of the board impedes transmission of Bluetooth signals. Lastly, there is a 5V plane on the board in the bottom left corner, as well as a 5VDC header for the connection from the board to the external power supply that also feeds the LED matrix. This 5V supplies the USB header for charging various devices, and can also power any other 5V device plugged in such as a fan if one is needed. The most important responsibility for this 5V line, however, is to allow the level conversion for the data line to occur successfully.

3.4 Heat

In order to provide power for the system, a series of regulators is implemented in the top right corner of the board. There is also a heat sink located on the top and bottom planes of the board, consisting of a .75x.75

inch square of 1oz copper pour. Heat proved to be a difficulty in the early stages of testing, where the 6V regulator would rapidly overheat and shut down. This was because the board was regulating a 24VDC signal to a 6VDC signal, using far more power than was intended for the individual regulator. The solution to this problem was simple, the power input to the board was initially a 24VAC signal, this has been changed to a 12VAC input, and as a result the power consumption by the regulator has decreased significantly and heat is no longer a problem.

3.5 Data Line

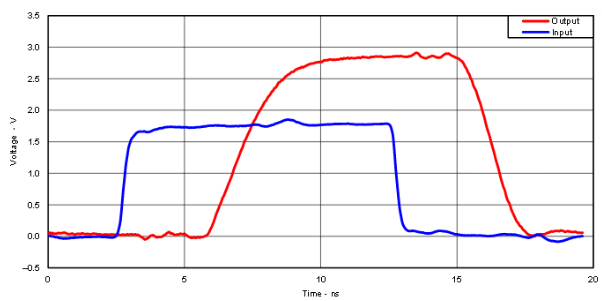


Fig. 4: Level Convert

The addressable RGB LEDs selected for this project (Adafruit Neopixels) are configured to receive a 5VDC signal. The output from the microcontroller, however, is a 3.3VDC signal. In order to ensure that the signal produced by the microcontroller is read properly by the LEDs in the display matrix, the voltage of that signal will be stepped up through a level converter. The level converter introduces a several nanosecond display that can be ignored for our application as seen below in figure 4 from the datasheet for the part (part number SN74LV1T34DBVR). The 5VDC level converted signal is then passed directly to the LED matrix through a wire that is connected to a header on the board.

4 Software Design

4.1 Flow

Figure 5 shows the general software initialization and control flow for this project. The basic design of the system is a semi modular purely software driven approach for most of the functions. This design was chosen due to the ease of swapping between the emulation environment and production. Additionally the design does have the capability to swap to an interrupt and hardware driven approach if the cycles are deemed needed.

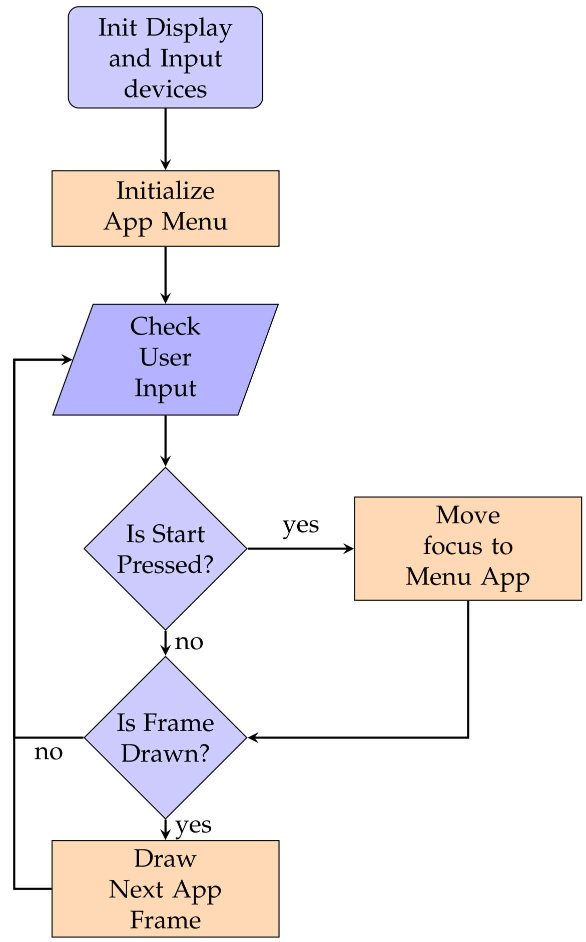


Fig. 5: Main Program Flow Logic

4.2 Display

The display driver is a key point in the software design as it is a timer sensitive and is a computationally expensive process due to the chosen LEDs. The main concept of driving the LEDs is divided into two sections; first being the actual communications the LEDs require and second being the software implementation of the LED communications. The LEDs (ws2812) require a pseudo PWM signal for communications with a 1 and 0 being differentiated by only their signals duty cycle. Also a reset signal (holding the line low) must be implemented as the LEDs are essentially latching shift registers that repeat the input signal after filling. Therefore to implement this it was deemed that using a standard interrupt driven system would be both optimal in terms of computation costs and speed as the communications protocol is highly variable and flexible. The software control of this is implemented inside the interrupt vectors generated by the timers; during the interrupt vector a bitmask is used on an structure containing the display data that is to

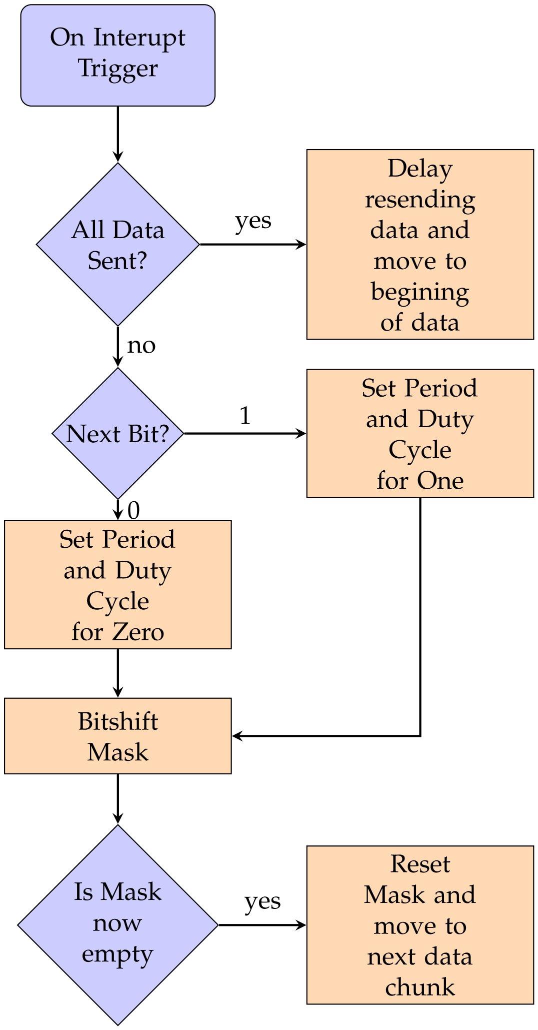
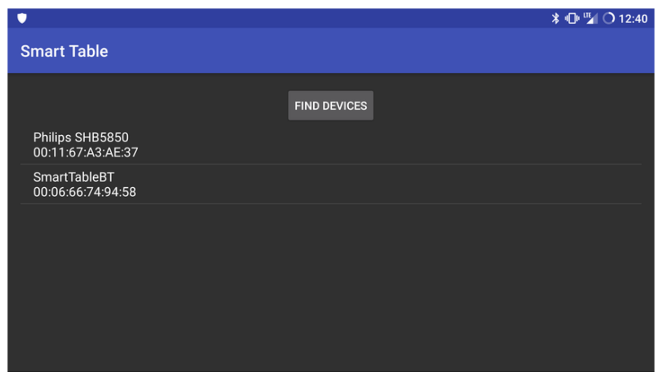


Fig. 6: Control Logic for the Display Driving

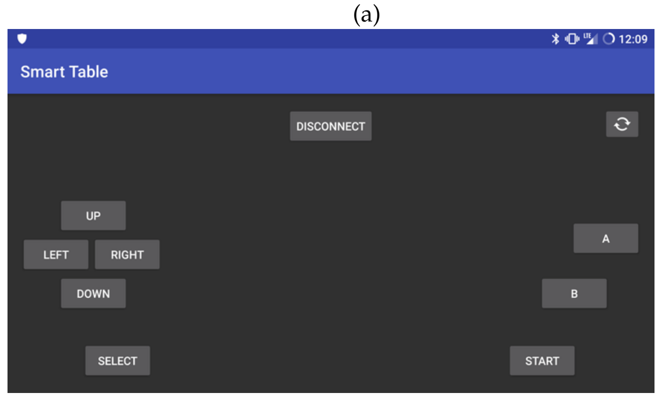
be sent and is rotated every interrupt until all the data is finished being sent for that ”frame”. As such this triggers 30 times a second (the max refresh rate of the LEDs) and takes a minimal amount of cycles due to the implementation.

4.3 Wireless Control

Bluetooth 2.1 is the method of wireless communication utilized by the Smart Table. Although a legacy protocol, Bluetooth 2.1 was chosen due to its stability and compatibility with millions of old and new devices alike. The Bluetooth connection is accomplished using the Roving Networks RN-42 Bluetooth module. The RN-42 is a low-cost device that supports the Serial Port Profile (SPP) to enable fast and robust pairing with mobile devices. It can transmit up to 4 dBm at 920 Kbps, receive with a -80 dBm sensitivity, and operates on 3.3 volts. Two RN-42 Bluetooth modules are connected to the microcontroller using the UART protocol configured with the ubiquitous 9600/8-N-1 serial port parameters: 9600 baud, 8 data bits, no parity bit, and one stop bit. The microcontroller supports up to three independent UART devices through the Texas Instruments Serial Communications Interface (SCI); they are SCI-A, SCI-B, and SCI-C respectively. The first module operates on the SCI-B and the second module operates on the SCI-C. As such, the modules are connected to a total of four GPIO pins on the microcontroller; two of them are multiplexed as inputs, and two are multiplexed as outputs. A level converter is not required since the Bluetooth modules and the microcontroller operate on the same 3.3 volt logic. The purpose of incorporating two Bluetooth modules is so that two individuals can play games with one another; a single Bluetooth module can only support one mobile device connection.



(a)



(b)

Fig. 7: (a) Device pairing screen. (b) Virtual gamepad.

4.4 Remote User Application

The open-source Android operating system was chosen as the ideal mobile platform to host a graphical user interface through which the Smart Table can be controlled remotely. The application, which can be seen in Figure 7, is written in the Java programming language and allows the user to issue commands using virtual buttons on the touch-screen display of the smartphone. When the virtual buttons are tapped, haptic feedback is sent to the user through the integrated vibration motor of the smartphone. This gives a natural feel to the user, in lieu of a physical remote with real buttons. The application can be comfortably used in either vertical or horizontal smartphone orientations. The button layout resembles that of modern video game controllers to provide the user with familiarity. A defining feature of the user application is that the Android operating system time and date can be synchronized with the microcontroller and subsequently drawn on the display.

In a typical scenario, a user will download and install the Smart Table Android application. Once the app is opened, the user will connect to one of the two Bluetooth connections, broadcasted as ”Player 1” and ”Player 2” respectively. Upon tapping a button, the associated command is translated into packets sent over the Bluetooth frequency-hopping spreading spectrum (FHSS) and stored in a data buffer. The data is then echoed to the UART transmit pin of the Bluetooth module. The microcontroller continuously polls the UART receive pin for a command, which is used to activate the various control flow statements in the main program of the microcontroller.

5 Software Applications

5.1 Procedural Image Generation

Implemented within the graphics processing control block are methods used for the procedural generation of images. Shown in figure 8 is a simulated output of a method used in the image generation upon the Smart Table; in particular the image is an example of using generated noise and ran through various algorithms to create a particular effect. The images shall be implemented using procedural methods due to the ease of scaling, memory concerns, and the visual interest that can be easily added by usage of such methods. As such various methods such as the implementation of shaders and blending must be optimized in terms of code size, ram costs, and computation costs. Though by taking this route it is unavoidable that the computation costs will be high for this implementation path. Additionally this path offers the greatest flexibility in terms of code reuse inside other functions, as none the of the patterns are hard-coded. Implemented in the code are various functions including; a text library, noise functions with various outputs and designs, generalized Bresenham line function, optimized filled circle function, empty circle, and a flood-fill function. As such with these building blocks the creation of a multitude of games and display functions can be built on-top with a minimal code space cost.

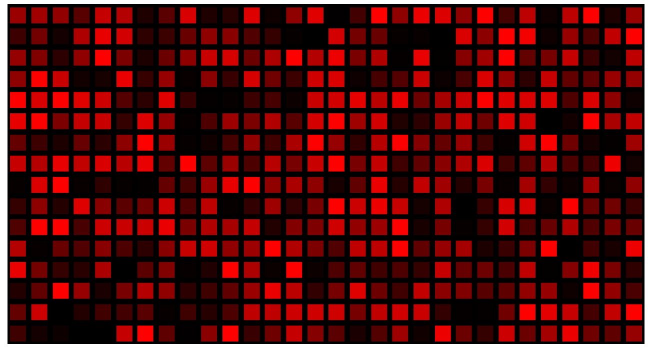


Fig. 8: Noise Generation

5.2 Games

Implemented additionally is a variety of games. Currently scheduled are Snake, Tron (lightcycles), Conways, Tetris, and the option is open to include other games. Also implemented on-board are two Bluetooth modules giving the option for multi-player support thus opening various avenues. A potential add-on function in the works is possible what is essentially ”etch-n-sketch” mode using the drawing functions listed earlier. As the software framework is designed to be modular there’s not much of an issue of adding on future expansions as long as there is enough flash and ram space, and the program is written in completely portable C.

6 Table Design

The Smart Table project is essentially an interactive coffee table interface. As such it follows the expected size constraints of a normal sized table, i.e. dimensions smaller that 4x8 feet while being shorter than 3 feet in height. The additional requirements required for the table design is the integration of dividers for the LEDs and on-top the dividers a diffuser is required for even distribution of light due to LED’s inbuilt dispersion pattern. Thus the base design can be cobbled together using a normal glass topped coffee table, the dividers made of possibly MDF board, and a top diffuser made of glass with a coating applied to it or frosted Plexiglas. All parts are easily sourced from local suppliers thus bringing total cost down. Though for this project the design was settled on, for construction by using a laser cutter. This allows for a unique design, acceptable amounts of structural integrity, and the inclusion of the dividers into the design itself. As shown in figure 9 the final of the table design uses the ”Flat-pack” design concept. Flat-pack, ready to assemble, or knock-down furniture is the stylistic choice for the final table design. As such the final product will

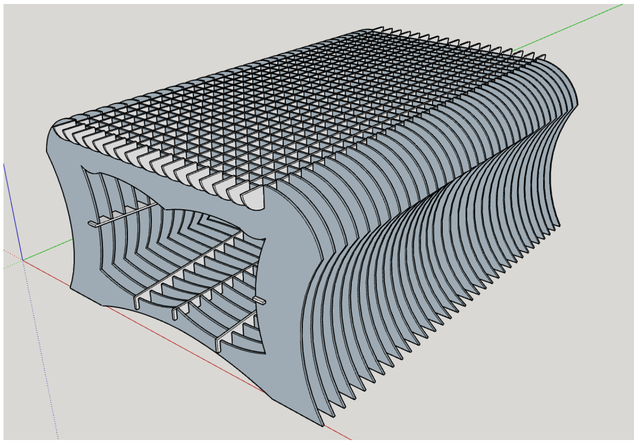


Fig. 9: 3D Render of Smart Table

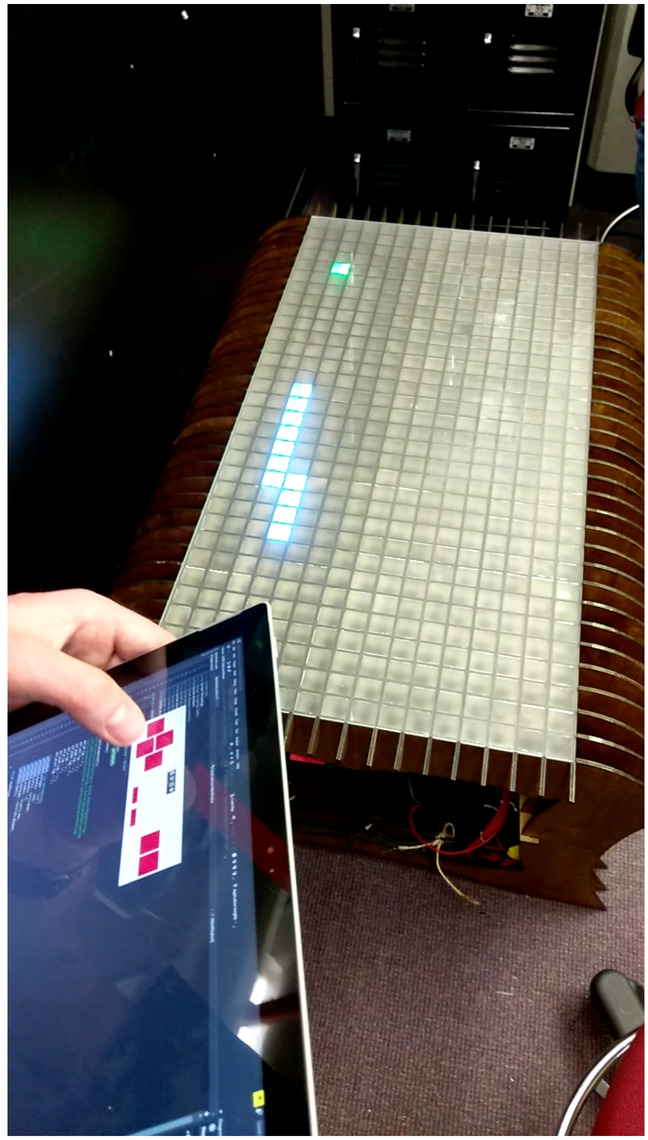


Fig. 10: Finished Table Displaying "Snake"

be laser cut for aesthetic reasons and assembly grounds. As laser cutting gives a markedly distinctive edging to the finished pieces and if a white wood is using the final construction is even more distinctive. Though the issue posed by the table using this construction method must be addressed and results with only flat pieces composing the design and thus making the construction into a puzzle. This issue though is also the main reason for the final decision in production. This stylistic construct is uncommon in normal affairs due to the cost of production and thus allows for a unique element to be added into the final product. As the cost of a laser cutter, time taken, and total wood cost is high for this style, products built using this idea are exceedingly unique and is required for this projects final success.

The tables dimensions are determined by the LED array's total size, the LED's light output parameters, and the physical limitations of using wood as the main construction element. Thus concerning the LED's light output considerations, the cells that are to house the LEDs are 1.5 x 1.5 inches and are 1.5 inches in depth to appropriately output the light within reasonable standards. Thus as the table is to be designed to comprise of an array of 16 x 32 this gives us (n+1) dividers as the cost in one dimension to create the necessary walls for light containment. Therefore, the total number of dividers would be 17 x 33 to have enough partitions to fittingly handle the job of limiting light bleed into neighboring pixels and containing the equipment from outside view and/or natural damage. This gives the total dimensions of the table to be of a bare minimum of 2 x 4 feet excluding the markup cost added by the dividers themselves. Thus as a consideration we have to account for the total size of the dividers and the integration of such into the final design. It is reasonable to assume that if the thinnest easily available wood is 1/10th of an inch and that the final product will not put any undue stress upon the construct, the new size total would become easily 25.7 x 51.3 inches, approximately 2.2 x 4.3 feet. The previously listed numbers all exclude issues with the physical limitations of the material available for usage.

Physical restrictions of wood itself must be addressed as the table itself is a load bearing construct and wood is not a material which acts the same in compression, tension, or along the grain. Due to the choice of using a laser cutting machine for construction, the wood itself is not something we have fine control over in terms of its grain, as we are dictated and controlled by the materials that are available and order-able within reasonable timeframes. Thus the simplest solution is to use plywood which is cheap, easily obtainable, can be found in a white wood such as birch, and solves the grain issue. Plywood is essentially smaller cuts of multiple types of wood or singular types that for each layer of wood the grain is orientated a direction and glued to another layer with its grain rotated 45, 90, or some other degree. This gives the final product a cheaper cost due to wood reuse and lower total quality required in the product; additional this also solves the issue of wood being easier to break along its grain, which once again due to the Smart Table's design is a core issue to be addressed earlier rather than later. This product comes in multiple layers depending on initial material used and thickness.

The table design chosen for the Smart Table integrates the dividers into the actual table itself and thus is all load bearing and therefore must account for the added stresses of expected load and its own weight. As a consequence this forces the size of the dividers to change into a thickness and material capable to handle such issues. Previously elaboration upon was plywood and thus it is the material to be chosen, in particular three layer birch wood based plywood which is the best material to hit the requirements of structural integrity and aesthetic concerns. The thickness of the material is 1/4th of an inch and therefore using previous definitions gives the table a minimum size of 28.25 x 56.25 inches or rounding approximately 2.5 x 5 feet, and assuming a height of 2 feet and a contiguous area, gives the total amount of wood to be in the range of 400 square feet. Therefore care must be given to optimization of the visual design in relation to the total cost of materials to bring down the total cost of the product without negatively affecting the visual stylistic choice within reason to obtain a viable balance.

Shown in figure 10 the prototype table design is complete. This took a large amount of effort due to the total laser time, staining, sanding, applying materials, soldering, and eventually assembly. As such this a prototype design and could be further iterated upon if the project is continued into the future. The design is complete and functional as per early SD2.

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