Proiectare cu MicroProcesoare - Project
- 2048 with Gyroscope -

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Contents

1 Introduction

The integration of technology into the education system has accelerated, presenting nearly limitless opportunities for fostering cognitive development in children of all ages.

Technology has the potential to enhance various skills, including language proficiency, fine motor skills, memory, and attention, making it an invaluable tool in educational settings.

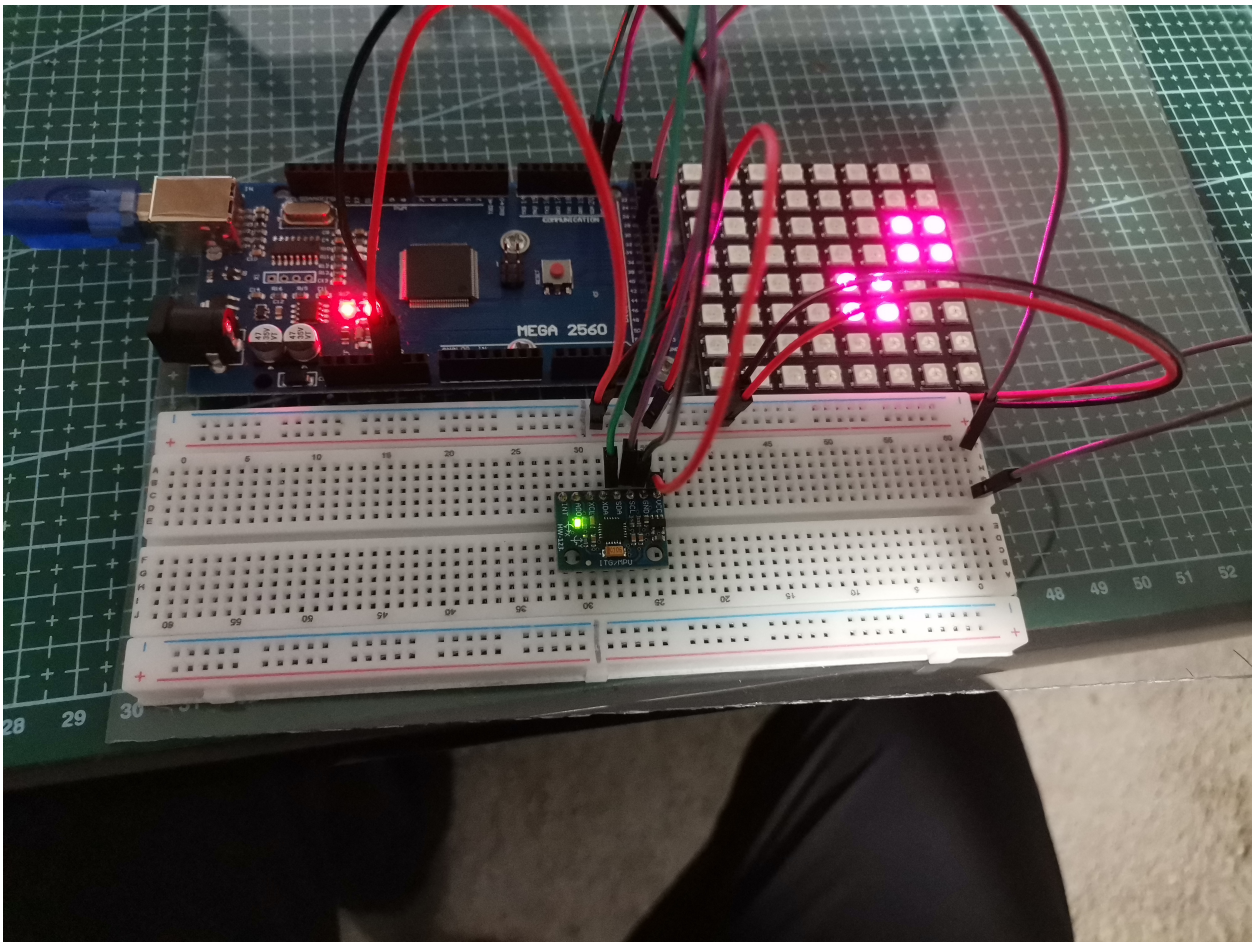
In light of this potential, this project proposes a solution aimed at the special education sector, specifically benefiting children with sensory and motor skill challenges, poor lateralization, and even older adults recovering from strokes.

The project employs a gyroscope sensor to detect inclination, calculate the state, and update the display, thereby illustrating key principles to children. Communication with the board is facilitated through the $\mathbf{I^2C}$ protocol.

To streamline the interaction between these components, predetermined libraries have been utilized.

To capture and maintain children's interest more effectively, an RGB palette has been chosen.

The primary goal is to enhance the therapy process in occupational therapy for children with special needs and to support their developmental progress.



2 Hardware

2.1 Components

2.1.1 Main Board

For the main board, an Arduino mega2560 was used. The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button [**arduino_2023_mega**].

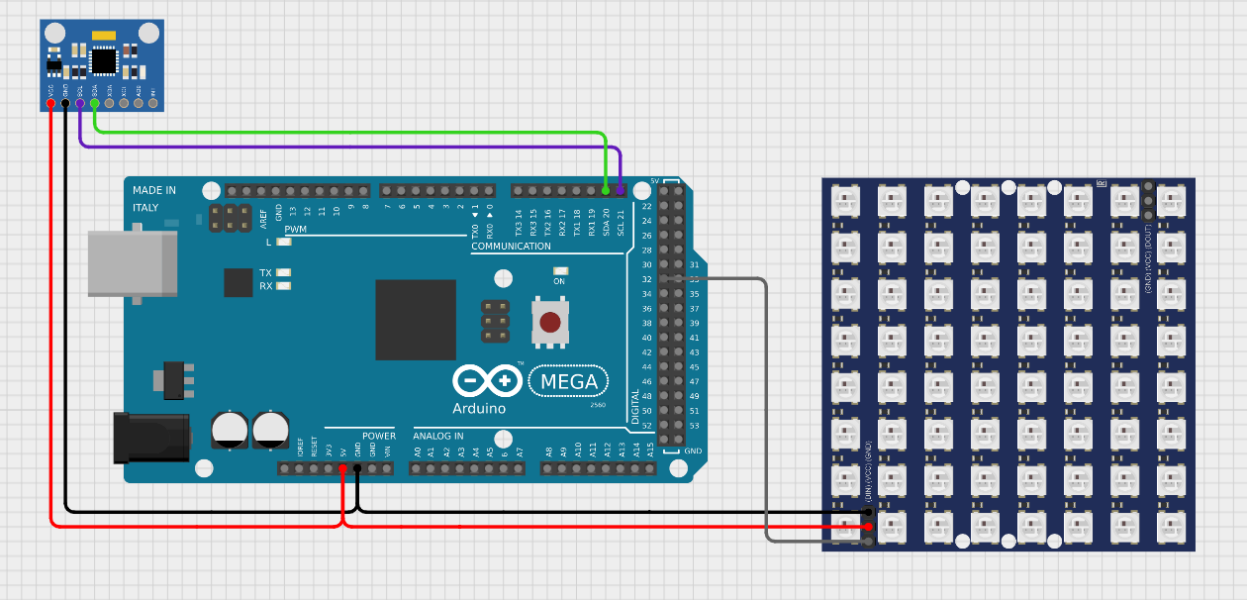
2.1.2 Input

For the input, an **MPU6050** was used. The **MPU6050** devices combine a 3-axis gyroscope and a 3-axis accelerometer on the same silicon die, together with an onboard Digital Motion Processor™ (DMP™), which processes complex 6-axis MotionFusion algorithms. The device can access external magnetometers or other sensors through an auxiliary master **I²C** bus, allowing the devices to gather a full set of sensor data without intervention from the system processor. [https://invensense.tdk.com/products/motion-tracking/6-axis/mpu-6050/]

2.1.3 Display

For the display, an **WS2812B** NeoPixel 8x8 Led Strip was used. Even if it is called a LED Strip, it is actually a matrix, but in the code is is still refered as an array.

2.2 Diagram



2.3 Connections

This symbol "**$**" will be used to indicate what color the pin has on the diagram so it's easier to follow along.

The common ports that both components use are **$VCC** and **$GND** . These connect to the dedicated **$VCC** and **$GND** ports on the board.

Out of the 8 ports the *input* has, only 4 are of intereset to us: **$VCC** , **$GND** , **$SCL** and **$SDA** .

$SCL (**clock**) is connected to digital port **21 (SCL)**
$SDA (**data**) is connected to digital port **20 (SDA)**
These are the ports of the **MPU6050** which communicate with the main board using the **I^2C** protocol.

The *display* has 3 ports: **$VCC** , **$GND** and **$DIN** .
$DIN is connected to digital port **32**, but it is configurable.
This is the port that controls the display, and where the data is sent.

3 Software

3.1 Code implementation

3.1.1 2048.h

```
#ifndef _2048_H
#define _2048_H

#include <stdbool.h>
#include <unistd.h>
#include <stdlib.h>
#include <time.h>
#include <string.h>

#ifndef TABLE_SIZE
# define TABLE_SIZE 4
#endif //TABLE_SIZE

typedef enum { left, down, up, right, } Direction;

void _2048_swipe             (int table[][TABLE_SIZE], Direction d); /* Call

void _2048_move              (int table[][TABLE_SIZE], int ref[][TABLE_SIZE],
void _2048_merge             (int table[][TABLE_SIZE], int ref[][TABLE_SIZE],
bool _2048_table_has_space   (int table[][TABLE_SIZE]);
bool _2048_table_has_changed(int table[][TABLE_SIZE], int old[][TABLE_SIZE]
void _2048_table_spawn       (int table[][TABLE_SIZE]);


#ifdef _2048_IMPLEMENTATION

int old[TABLE_SIZE][TABLE_SIZE];

void _2048_swipe(int table[][TABLE_SIZE], Direction d)
{
    int x0, xn, dx;
    int y0, yn, dy;

    switch(d)
    {
        case left:
            x0 = 0           ; xn = +TABLE_SIZE; dx = +1;
            y0 = 1           ; yn = +TABLE_SIZE; dy = +1;
            break            ;
```

```
40
41          case right:
42              x0 = 0            ; xn = +TABLE_SIZE; dx = +1;
43              y0 = TABLE_SIZE-2; yn = -1          ; dy = -1;
44              break             ;
45
46          case down:
47              x0 = TABLE_SIZE-2; xn = -1          ; dx = -1;
48              y0 = 0            ; yn = +TABLE_SIZE; dy = +1;
49              break             ;
50
51          case up:
52              x0 = 1            ; xn = +TABLE_SIZE; dx = +1;
53              y0 = 0            ; yn = +TABLE_SIZE; dy = +1;
54              break;
55
56          default: break; //unreachable
57      }
58
59      // we need this to check if the table has changed
60
61      memcpy(old, table, TABLE_SIZE*TABLE_SIZE*sizeof(int));
62      // ref is used to not merge a recently merged cell with another
63      // as an example we can image we swipe right on the following:
64      // * 4 4 2 2
65      // we want the output to be
66      // * 0 0 8 4
67      // not
68      // * 0 0 4 8
69      int ref[TABLE_SIZE][TABLE_SIZE];
70
71      for (int x = x0; (dx > 0 ? x < xn : x > xn); x += dx)
72          for (int y = y0; (dy > 0 ? y < yn : y > yn); y += dy)
73              if (table[x][y])
74                  _2048_merge(table, ref, x, y, d);
75      memset(ref, 0, TABLE_SIZE*TABLE_SIZE*sizeof(int));
76
77      for (int x = x0; (dx > 0 ? x < xn : x > xn); x += dx)
78          for (int y = y0; (dy > 0 ? y < yn : y > yn); y += dy)
79              if (table[x][y])
80                  _2048_move(table, ref, x, y, d);
81
82      if (_2048_table_has_changed(old, table))
83          _2048_table_spawn(table);
84
```

```
85  }
86
87  void _2048_merge(int table[][TABLE_SIZE], int ref[][TABLE_SIZE], int x, int
88  {
89      int ox, oy; // offset
90      int ax, ay; // activate x y or k
91      int k0, kn, dk; // for(int k = k0; k < kn; k += dk)
92      switch(d)
93      {
94          case left:  ax =  1; ay =  0; ox = x  ;   oy = y-1;     k0 = y-1;  k
95          case down:  ax =  0; ay =  1; ox = x+1;   oy = y  ;     k0 = x+1;  k
96          case up:    ax =  0; ay =  1; ox = x-1;   oy = y  ;     k0 = x-1;  k
97          case right: ax =  1; ay =  0; ox = x  ;   oy = y+1;     k0 = y+1;  k
98          default: break;
99      }
100
101     for (int k = k0; (dk > 0 ? k < kn: k > kn); k += dk)
102     {
103         int cx  = ax*ox + ay*k;
104         int cy  = ay*oy + ax*k;
105         if (table[cx][cy])
106         {
107             if (table[cx][cy] == table[x][y] && ref[cx][cy] != 1)
108             {
109                 table[cx][cy] += table[x][y];
110                 ref[cx][cy] = 1;
111                 table[x][y] = 0;
112                 return;
113             }
114             return;
115         }
116     }
117     return;
118 }
119
120 void _2048_move(int table[][TABLE_SIZE], int ref[][TABLE_SIZE], int x, int
121 {
122     int ox, oy; // offset
123     int ax, ay; // activate x y or k
124     int k0, kn, dk; // for(int k = k0; k < kn; k += dk)
125     switch(d)
126     {
127         case left:  ax =  1; ay =  0; ox = x  ; oy = y-1;     k0 = y-1; kn
128         case down:  ax =  0; ay =  1; ox = x+1; oy = y  ;     k0 = x+1; kn
129         case up:    ax =  0; ay =  1; ox = x-1; oy = y  ;     k0 = x-1; kn
```

```
130             case right: ax =  1; ay =  0; ox = x  ; oy = y+1;     k0 = y+1; kn =
131             default: break;
132         }
133
134         for (int k = k0; (dk > 0 ? k < kn + 1 : k > kn - 1); k += dk)
135         {
136             int cx  = ax*ox + ay*k;
137             int cy  = ay*oy + ax*k;
138             int cxk = ax*ox + ay*(k-dk);
139             int cyk = ay*oy + ax*(k-dk);
140             /* if (obstacle) */
141             // obstacle may mean:
142             // 1. cell right after current cell
143             // 2. cell up until the last legal cell (including)
144             // 3. outside boundry cell (imaginary)
145             if (table[cx][cy])
146             {
147                 table[cxk][cyk] = table[x][y]; // 2
148                 if (k != k0) // 1
149                     table[x][y] = 0;
150                 return;
151             }
152             if (k == kn) // 3
153             {
154                 table[cxk][cyk] = table[x][y];
155                 table[x][y] = 0;
156                 return;
157             }
158         }
159         return;
160 }
161
162 bool _2048_table_has_changed(int table[][TABLE_SIZE], int old[][TABLE_SIZE])
163 {
164     for (int i = 0; i < TABLE_SIZE; i++)
165         for (int j = 0; j < TABLE_SIZE; j++)
166             if (table[i][j] != old[i][j])
167                 return true;
168     return false;
169 }
170
171 bool _2048_table_has_space(int table[][TABLE_SIZE])
172 {
173     for (int i = 0; i < TABLE_SIZE; i++)
174         for (int j = 0; j < TABLE_SIZE; j++)
```

```
175             if (table[i][j] == 0)
176                 return true;
177     return false;
178 }
179
180 void _2048_table_spawn(int table[][TABLE_SIZE])
181 {
182     bool generated = false;
183     if (_2048_table_has_space(table))
184     {
185         while(!generated)
186         {
187             int x = rand()%TABLE_SIZE;
188             int y = rand()%TABLE_SIZE;
189             if (!table[x][y])
190             {
191                 int number;
192                 int r = rand();
193                 if (r % 10 < 9 )
194                     number = 2;
195                 else
196                     number = 4;
197                 table[x][y] = number;
198                 generated = true;
199             }
200         }
201     }
202 }
203
204 #endif //_2048_IMPLEMENTATION
205
206 #endif // _2048_H
```

3.1.2 Main program

```
/*
 * Configuration
 */
#define TABLE_SIZE 4
#define _2048_IMPLEMENTATION
#include "2048.h"
int table[TABLE_SIZE][TABLE_SIZE];
typedef enum {
      flat = 0,
      l, d, u, r
} Orientation;

#include <FastLED.h>
#define LED_PIN 32
#define LED_BRIGHTNESS 40 // 0-255
#define LED_COUNT 64
CRGB leds[LED_COUNT];

#include <basicMPU6050.h>
basicMPU6050<> mpu;

#define seed() random()
void setup()
{
        Serial.begin(9600);
        Serial.println("");
        Serial.println("Initializing");
        Serial.println("");
        srand(seed());
        _2048_table_spawn(table);
        _2048_table_spawn(table);

        Serial.println("Setting up MPU6050...");
        mpu.setup();
        mpu.setBias();
        Serial.println("Done.");

        Serial.println("Setting up leds...");
        FastLED.addLeds<WS2812B, LED_PIN, GRB>(leds, LED_COUNT);
        FastLED.setBrightness(LED_BRIGHTNESS);
        Serial.println("Done.");

}
```

```
44
45  /*
46   * Logic
47   */
48  CRGB cell_color(int x)
49  {
50          if (x) return CHSV(7*x%360-30, 255, 255);
51          else   return CHSV(0, 0, 0);
52  }
53
54  void draw_cell(int number, int x, int y)
55  {
56          CRGB color = cell_color(number);
57          leds[(2*x+0)*8 + (2*y+0)] = color;
58          leds[(2*x+0)*8 + (2*y+1)] = color;
59          leds[(2*x+1)*8 + (2*y+0)] = color;
60          leds[(2*x+1)*8 + (2*y+1)] = color;
61
62  }
63
64  void display(int table[][TABLE_SIZE])
65  {
66          for (int i = 0; i < TABLE_SIZE; i++)
67                  for (int j = 0; j < TABLE_SIZE; j++)
68                          draw_cell(table[i][j], i, j);
69          FastLED.show();
70  }
71
72  #define THRESHOLD 0.7
73  bool sub(float f) { return (-THRESHOLD < f && f < +THRESHOLD); }
74  bool sup(float f) { return (-THRESHOLD > f && f > +THRESHOLD); }
75
76  Orientation getOrientation()
77  {
78          Orientation o;
79          mpu.updateBias();
80          if (sup(mpu.ax()) && sub(mpu.ay()) && sub(mpu.az())) o = flat;
81          if (sub(mpu.az()) && mpu.ax() < -THRESHOLD) o = u;
82          if (sub(mpu.az()) && mpu.ay() < -THRESHOLD) o = l;
83          if (sub(mpu.az()) && mpu.ax() > +THRESHOLD) o = d;
84          if (sub(mpu.az()) && mpu.ay() > +THRESHOLD) o = r;
85          return o;
86  }
87
88  Orientation prev_orientation = flat;
```

```
89  void loop()
90  {
91          Serial.print("loop ");
92          display(table);
93          Orientation curr_orientation = getOrientation();
94          if (curr_orientation != prev_orientation)
95                  switch (curr_orientation)
96                  {
97                          case l: _2048_swipe(table, left);  Serial.println("
98                          case d: _2048_swipe(table, down);  Serial.println("
99                          case u: _2048_swipe(table, up);    Serial.println("
100                         case r: _2048_swipe(table, right); Serial.println("
101                         case flat: Serial.println("flag");
102                 }
103
104         prev_orientation = curr_orientation;
105 }
```

3.2 Code description

3.2.1 2048.h

`2048.h` is a single header library, where common functions for the 2048 game are immplemented, such as swipe, spawn, merge, has space, etc.

3.2.2 FastLED

Multi-platform library for controlling dozens of different types of LEDs along with optimized math, effect, and noise functions. `FastLED` is a fast, efficient, easy-to-use Arduino library for programming addressable LED strips and pixels such as WS2810, WS2811, LPD8806, Neopixel and more. FastLED also provides high-level math functions that can be used for generative art and graphics. [https://docs.arduino.cc/libraries/fastled/]

3.2.3 basicMPU6050

lightweight library for the MPU6050. library to configure and retrieve the raw sensor outputs of the MPU6050. It includes simples routines to calibrate the gyro. [https://docs.arduino.cc/libraries/basicmpu6050/]

3.2.4 setup

The `setup` function initializes the three essential components of the software.

3.2.5 display

The `display()` function is designed to render the game table on the LED matrix. It utilizes the `draw_cell()` function, which is responsible for drawing individual cells on the LED matrix.

The color of each cell can be configured using the `cell_color()` function.

3.2.6 input

The `getOrientation()` function determines the orientation of the sensor. Its sensitivity can be adjusted by modifying the value of the `THRESHOLD` macro.

3.2.7 loop

The `loop()` function serves as the main event loop of the program, coordinating the execution of all other functions. It updates the display, retrieves the current orientation, and updates the game state using the swipe functions from the `2048.h` library.

4 Testing

4.1 Configuration

4.1.1 2048.h

The first component included is the game logic, which resides in the file *2048.h*. As *2048.h* is a single-header library, the `_2048_IMPLEMENTATION` macro must be defined to ensure that the library includes the implementations of the game functions, rather than just their declarations.

After this, a declaration of the game table is made, which will store the state of the game. The direction enumeration type from *2048.h* is extended to include the **flat** position and is renamed to `Orientation` accordingly.

4.1.2 FastLED.h

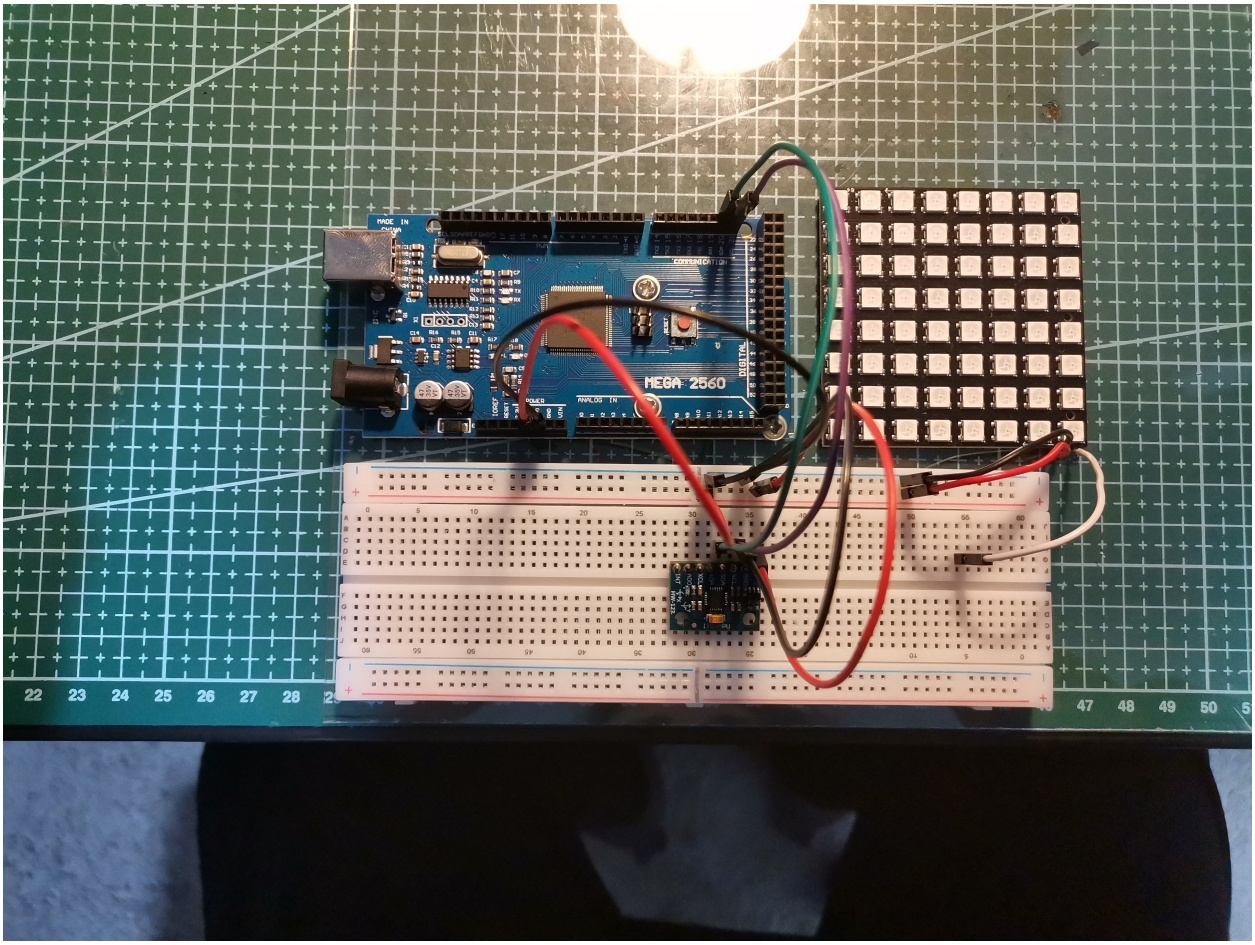
The next library included is *FastLED.h*, which allows communication with the display. The `LED_PIN` is configured and assigned to pin `32`; this can be changed to any other port as needed. The `LED_BRIGHTNESS` ranges from `0-255`, and an arbitrary value of `16` has been chosen, but it can be adjusted as required. The `LED_COUNT` is set to `64`, reflecting the number of LEDs in the display. Following this, the `leds` array is defined with a length matching `LED_COUNT`.

4.1.3 basicMPU6050.h

The next library, *basicMPU6050.h*, makes it easy to communicate with the MPU6050 sensor. An object named `mpu` is created to handle this interaction.

4.1.4 Setup

In the `setup` function, the random number generator (RNG) is initialized. The 2048 game table is set up with two tiles. The display and gyroscope are then configured.



4.2 Logic

4.2.1 Display

The `display()` function processes each row and column of the game table, calling the `draw_cell()` function for each cell. Once completed, it calls `FastLED.show()` to refresh the display. The `draw_cell()` function assigns colors based on the current values in the game table to show on the display. Additionally, a function named `cell_color` is used to return a color based on the input number, using a predefined formula that can be adapted.

4.2.2 Input

The `getOrientation()` function retrieves inclination information from the accelerometer by calling the methods `mpu.ax()`, `mpu.ay()`, and `mpu.az()`. It compares these values against a configurable `THRESHOLD`. The function utilizes two helper methods, `sup()` and `sub()`, which verify whether a value falls within the specified `THRESHOLD`.

4.2.3 Loop

The first action carried out by the `loop()` function is to display the current state of the game table. It then obtains the current orientation and compares it with the previous orientation. If a difference is found, the function determines the current orientation using a `switch` statement and calls the appropriate function from `2048.h`. Finally, it updates the `prev_orientation` variable.