THE COOPER UNION FOR THE ADVANCEMENT OF SCIENCE AND ART

# Marble Match

## Ph 215 Microcontroller Projects in Physics

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# CONTENTS

# ABSTRACT

"Marble Match" is a game designed specifically for autistic children, with the intent of engaging these children despite their disability. Because autistic children often have short attention spans and become bored or frustrated by games that other children enjoy, Marble Match is intended to be an extremely simple game which offers a clean and attractive visual reward for completing the task of the game. It involves matching colored marbles to the color of an LED that light up. If the correct color marble is inserted into the correct hole, a series of IR sensors, a color sensor, and a servo motor check and consequently channel the marble to a transparent helical tube which constitutes the visual reward.

# INTRODUCTION

Marble Match is a two foot tall tower with a square foot base constructed out of transparent polycarbonate, allowing the user to see inside the tower. The top face of the tower has four holes roughly at the midpoint of each side of the square with an RGB LED embedded in the face next to each hole. The game play is as follows: after the game is turned on, one random LED will turn on to display a random color (out of red, green, yellow or blue). The task of the user will be to choose the same color marble out of a container or red, green, yellow, and blue marbles and consequently insert it into the specific hole adjacent to the lit LED. The hole the marble was inserted into is determined by a series of infrared (IR) sensors constructed out of an IR LED and an IR sensitive phototransistor, and the color of the marble is determined by an Avago ADJD-S371-Q999 color sensor and evaluation board. Both of these electronic components, along with a ROB-09065 servo motor are controlled by an Arduino Duemilanove. Incorrectly matched marbles are channeled into a black tube which ejects them from the base of the tower, while correctly matched marbles spiral down a transparent helical vinyl tube from 1.5 ft above the base of the tower.

The spiraling motion of colored marbles is a visually pleasing reward which can captivate children without flashing lights and loud sounds, both of which often aggravate autistic children. The game teaches basic colors and the concept of matching, but more importantly can allow children to learn patience and diligence. Marble Match can be a calming activity for autistic children and demonstrates a simple, positive application of the Arduino microcontroller.

# PHYSICAL DESIGN

## Exterior

The exterior of Marble Match is constructed out of 2’x1’x ½ inch thick transparent polycarbonate sheets cut to make the faces of the tower and screwed together as shown in Drawing 1.1 and Figure 1. The important features of the exterior design are the gap at the bottom of the tower for marbles to exit and the four holes in the top face for marble insertion.

## Interior

The interior of the Marble Match tower is designed to channel marbles to the appropriate location. Upon insertion, a marble rolls down a slightly inclined ramp made out of $\frac{1}{8}$ inch polycarbonate and held in place by four screw-and-nut fixtures hanging down from the roof of the tower, as can be seen in Figure 2. The marble is then diverted to a hole in the ramp which lies directly above the insertion hole of the color sensing box, allowing the marble to drop down and roll to a point directly under the color sensor, where it is held in place by a servo-controlled metal gate, shown in Figure 3. After the color sensor evaluates the color of the marble, the servo rotates the gate either to divert the marble down the transparent, helical tube (if the color and insertion hole are correct) or the black plastic tube (if the color or insertion hole are incorrect). The helical tube is glued to the larger polycarbonate cylinder to maintain its shape using a silicone caulk for polycarbonates, and the black tube is simply glued to the front face of the tower.

## Color Sensing Box

The black color sensing box is a 3” x 4” x 1.25” sized box constructed out of ¼ inch thick black polycarbonate as seen in Drawing 2.1. It is designed to provide a relatively dark and therefore controlled environment for the color sensor to operate. Other than the two openings to accept and eject marbles, the only light source for the color sensor is an LED on the evaluation board itself. The color sensor is attached to the inside face of the top of the box such that it can look down on marbles without any risk of being damaged. Its power and control leads are soldered to wires that come out of the roof of the box.

# ELECTRONICS

## Color Sensor

The Avago ADJD-S371-Q999 color sensor evaluation board has 7 pins, as seen in Figure 4. An important note in employing this device is that it runs on 3.3V rather than 5V, although 5V is within its functional range. The SCL and SDA lines are connected to pins A5 and A4 as usual in using a I2C serial device, and the on-board LED is on whenever the Arduino is on, as it is connected directly to 5V.

Upon turning on the Arduino, the color sensor requires calibration to optimize its sensitivity to the lighting conditions in its surroundings. This calibration process entails reading the four "Gain" registers on the color sensor and then adjusting capacitors on the color sensor to optimize the output of the sensor. The data the evaluation board outputs is in the form of integer numbers representing each of four values: clear (cc), red, green, and blue. In order to improve precision, this measurement is performed 50 times and the values averaged together before they are evaluated for the color of the marble.

## IR Sensors

The IR sensors are each constructed out of an IR LED and an IR sensitive phototransistor. In each sensor, an LED and a phototransistor are fit into small, roughly ½" cube-shaped scraps of black polycarbonate, as shown in Figure 5. These are attached on either side of the hole through which the marble will be inserted such that the top of the LED directly faces the top of the phototransistor, and the maximum amount of IR light hits the phototransistor, as shown in Figure 6. A model circuit of the sensors is shown in Figure 7.

When the IR light beam between the LED and phototransistor is uninterrupted, the base pin of the phototransistor remains at an analog high, between .45 V and .50 V. However, when a marble or any other obstruction interrupts the beam, the voltage on the base pin dips under .10 V.

Because there are five IR sensors and only three available analog pins, an external comparison mechanism was implemented. First, the output from all five base pins from the phototransistors are converted to digital outputs via three dual LM358N op-amps, which compare the voltage on the base pins to the voltage from a potentiometer, adjusted to about .40 V, seen in Figure 4. After this conversion, the outputs from the op-amps are put through a quad dual-input OR chip (CD4071BE) to yield a 3-bit number indicating the status of all five IR sensors. The logic equations employed are X=A+B, Y=C+B, and Z=A+E+C, where A, B, C, D, and E are the IR sensors, and X, Y, and Z are the three bits of the output. The three outputs are then fed to pins 1, A1, and A2, and are read as digital inputs.

## RGB LEDs

The four RGB LEDs each have three power pins and one ground pin. The power pins, 12 in all, are connected to digital pins 2 to 13 through 1K Ω resistors. The values of these resistors can be altered to change the intensities of the colors. The LEDs are therefore directly controlled by the Arduino, even though this consumes a large number of digital pins.

# FUTURE DEVELOPMENTS

Marble Match can be developed by improving both the physical and electronic design. The physical design can be made more child-friendly by eliminating the sharp edges of the tower, and the design of the black color sensor box can be improved to make machining it easier, as well as to keep light out better. The IR sensors can be improved by implementing more effective photodiodes or phototransistors or by optimizing the physical design of the sensors to make them more effective at detecting marbles. The algorithm by which the color sensor determines color – that is, the determinecolor() function – can also be improved through extensive testing of the sensor. The mass of wires under the roof of the tower can be eliminated to provide a cleaner design by creating a PCB or a shield for the Arduino. Finally, different games using the existing setup can be programmed onto the Arduino, such as a “simon” game. The user can be given control over the game in play as well as the difficulty of the game via a series of switches.

## ACKNOWLEDGMENTS

The development and implementation of this project was supported by several people, including members of the Cooper Union staff. Yonah Kupferstein helped design the electronics, especially the use of the CD4071BE OR chip to read the IR sensors despite the lack of analog pins. Both Professor Alan Wolf and Vinaya Phadke helped develop the game play and concept of Marble Match, and provided advice about many key components of the project. Finally, Sinisa Janjusevic, the Faculty Machine Shop Technician, provided a tremendous amount of support with the physical construction of Marble Match.

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## Appendix I – PARTS LIST

| **Electronic Components** | | | | | |
|---|---|---|---|---|---|
| **Component** | **Model** | **Link** | **Quantity** | **Unit Price** | **Other** |
| Arduino Duemilanove | | | | | |
| Color Sensor and Evaluation Board | Avago ADJD-S371-Q999 | http://www.sparkfun.com/products/8663 | 1 | $19.95 | |
| Servo Motor | ROB-09065 | http://www.sparkfun.com/products/9065 | 1 | $___ | |
| Phototransistor | | | 4 | - | IR sensitive |
| Infrared LED | | | 4 | - | |
| RGB LED | COM-00105 | http://www.sparkfun.com/products/105 | 4 | $1.95 | Triple output LED |
| Dual Op-Amp | LM358N | | 3 | - | |
| Quad dual-input OR chip | CD4071BE | | 1 | - | |
| Assorted resistors, transistors, and switches | | | | | |

| **Physical Components** | | | | | |
|---|---|---|---|---|---|
| **Component** | **Model** | **Link** | **Quantity** | **Unit Price** | **Other** |
| Marbles | Chinese Checkers Marbles | http://tinyurl.com/6kqbey6 | 1 | $9.95 | 6 colors, 14mm |
| Plastic Tubing | DiversiTech SKU: 7-78 | http://www.pexsupply.com/DiversiTech-7-78-7-8-ID-Clear-Vinyl-Tubing-50 | 50 ft | $18/50ft | |
| Polycarbonate Sheet | 8574K45* | http://www.mcmaster.com/#polycarbonate-sheet-stock/=b9gp4p | 5 | $46.74/ft$^2$ | 24"x12" Rectangular Sheet |
| Black Polycarbonate | 85625K23* | http://www.mcmaster.com/#polycarbonate-sheets/=bhbxtj | 1 | $40.71/ft$^2$ | 12"x12" Square Sheet |
| Polycarbonate cylinder | 8585K48* | http://www.mcmaster.com/#polycarbonate-sheets/=b9gso7 | 2 ft | $38.78/ft | ¼ in thick |
| Assorted screws, metal scraps, silicone caulk, and acrylic solvent | | | | | |
| | | | **Total** | **$407.67** | |

*indicates a Model number specifically from www.mcmaster.com

# APPENDIX II - FIGURES

**Figure 1 - Full Tower**


**Figure 2 - Close Up of Ramp**

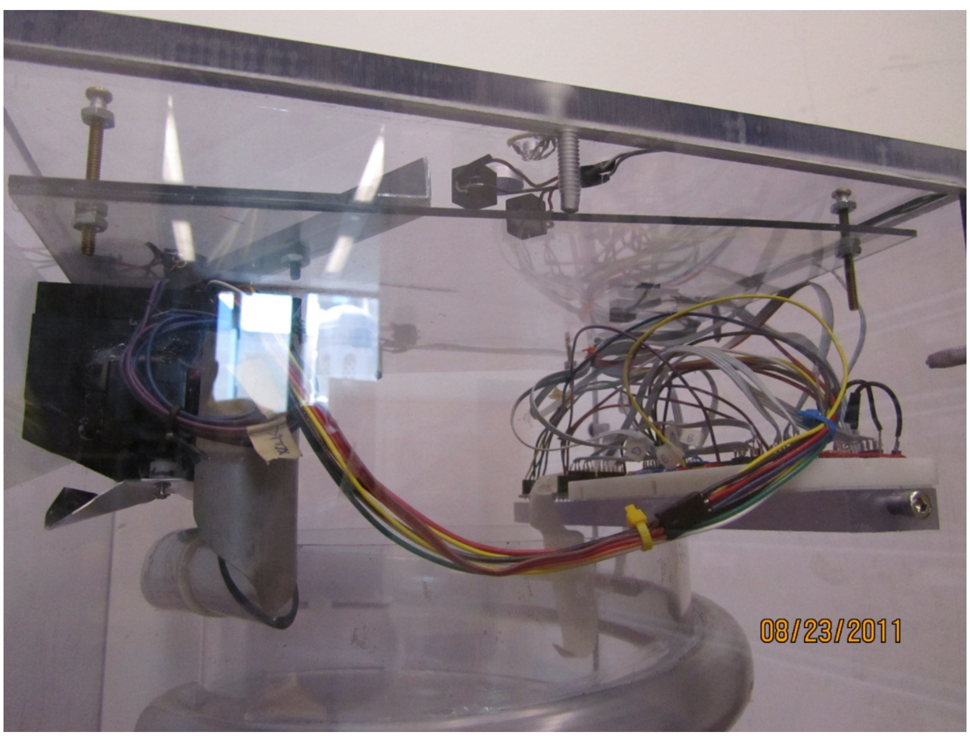


**Figure 3 - Servo Controlled Gate**

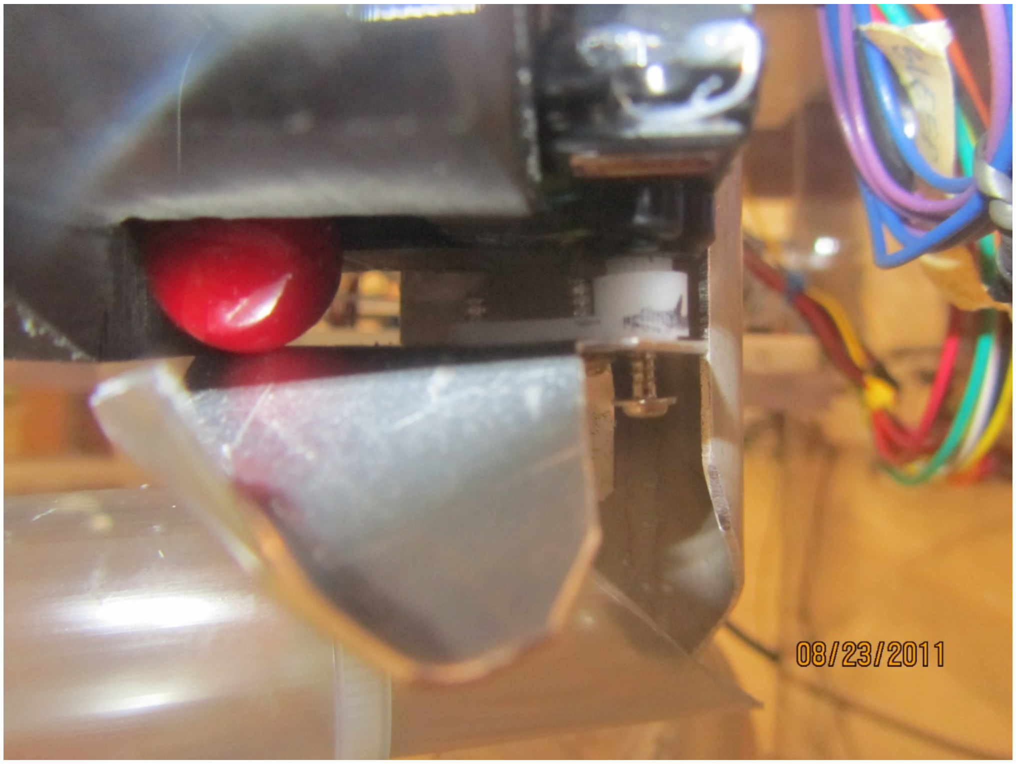
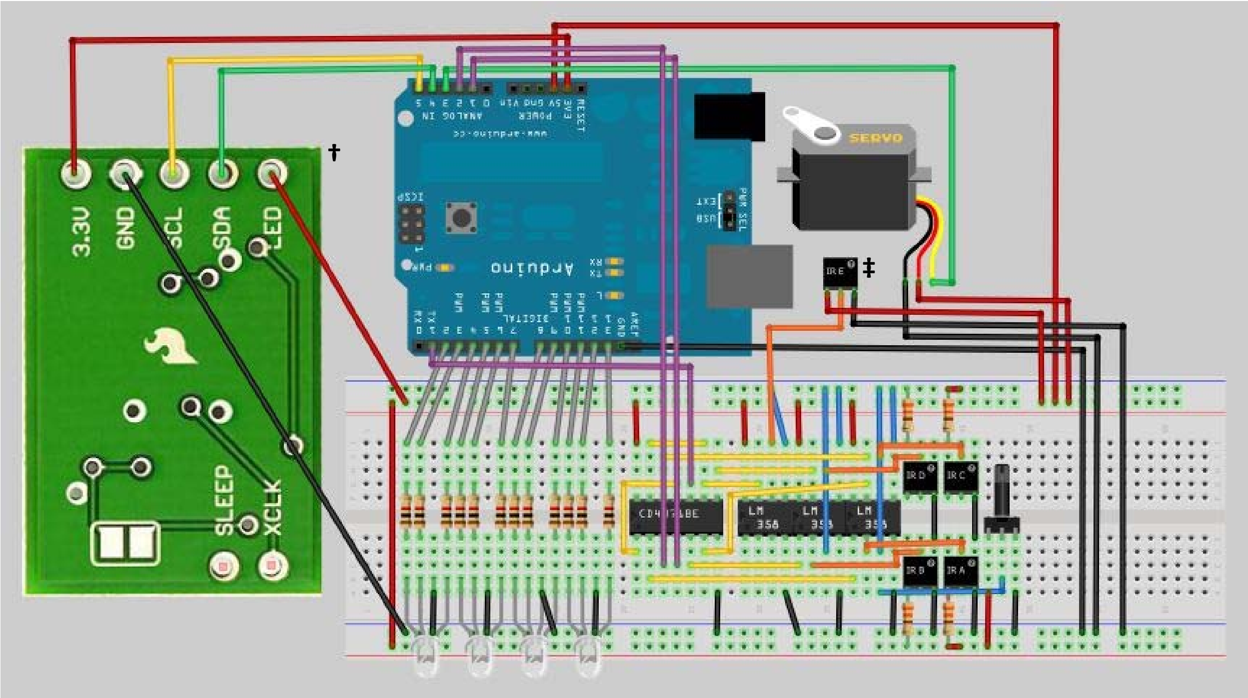



**Figure 4 – Fritzing of Circuit**




† Avago ADJD-S371-Q999 not to scale

‡ IR Sensor package abbreviated – see Figure 7

**Figure 5 - IR Sensor (top view)**


**Figure 6 - IR Sensor (side view)**