_____

Partitive Mixing of Colours Interactive Device

Ricardo Veiga, Raquel Correia, João Sena Esteves
Department of Industrial Electronics
University of Minho, Campus of Azurém, 4800-058 Guimarães, Portugal
ricardo_elmdv@hotmail.com, s_rakel_correia@hotmail.com, sena@dei.uminho.pt

Abstract. *Rotating a disk with differently coloured sectors is a well-known means of achieving partitive mixing of colours. Most educational devices applying this technique use a single motor that spins only one disk at a time, requiring different disks to be swapped between them. This paper describes an interactive device equipped with five motors, each one holding its own disk. These motors can be switched on individually, allowing more than one disk to rotate at the same time. Some fundamentals on colour mixing are introduced. A few construction details are given, too. The device, built for a science exhibition, has also been used in the classroom.*

Keywords. Additive mixing, colour mixing, colour science, Maxwell disks, Maxwell Triangle, Newton's Colour Circle, partitive mixing, RGB.

1. Introduction

Partitive mixing of colours is a type of *additive mixing of colours* and can be achieved by a spinning disk with differently coloured sectors. Most educational devices with such rotating disks use a single motor fitted with an adaptor capable of holding only one disk at a time. So, different disks must be swapped between them. This paper describes an interactive device equipped with five motors, each one holding its own disk. These motors can be switched on individually, which allows more than one disk to rotate at the same time.

The device (Fig. 1) was built for the *Mostra Interactiva de Ciência e Tecnologia*[1] (Interactive Exhibition of Science and Technology) – integrating part of the *Projecto Ciência na Cidade de Guimarães* (Science in Guimarães City Project). Since then, it has been used in

science exhibitions and classroom demonstrations in several schools.

Section 2 introduces some fundamentals on colour mixing. Section 3 lists the main materials used to build the device. Section 4 gives some details on the construction and operation of the device. Section 5 contains the conclusions of the paper. After the acknowledgements in Section 6, a list of references is given in Section 7.

2. Colour Mixing

It is common knowledge that mixing blue and yellow paints produces green paint. However, mixing proper amounts of blue and yellow lights produces a white light (Fig. 2). In fact, there is a fundamental difference between mixing pigments or dyes and mixing lights.

Figure 1. Showing the Partitive Mixing of Colours Interactive Device in the *Mostra Interactiva de Ciência e Tecnologia* (Interactive Exhibition of Science and Technology)

Mixtures of pigments or dyes are, usually, complicated processes which results are ruled by their power to subtract certain regions of the spectrum from the incident light [1, 2, 3]. For this reason, the mixing of pigments or dyes is called *subtractive colour mixing*.

_____

[1] *Mostra Interactiva de Ciência e Tecnologia*, Palácio Vila Flor, Guimarães, Portugal, April 14 – 20, 2008.

_____

This paper resulted from a communication presented at HSCI2008' Conference, Olinda, Brazil, October 13 to 17, 2008.

_____

The wavelengths of two or more coloured lights seen together are added. So, the mixing of coloured lights is called *additive colour mixing* [1, 2, 3].

Additive mixing of different quantities of red, green and blue colours produces a wide range of colours, which can be displayed inside an RGB Maxwell Triangle (Fig. 3).
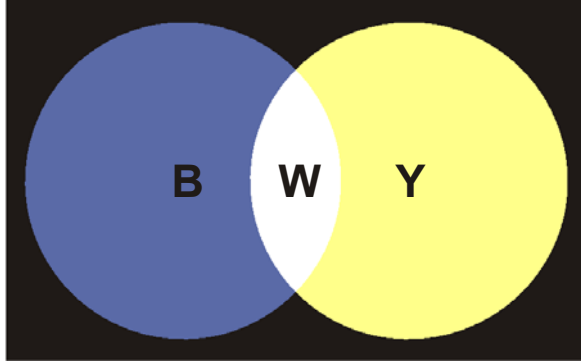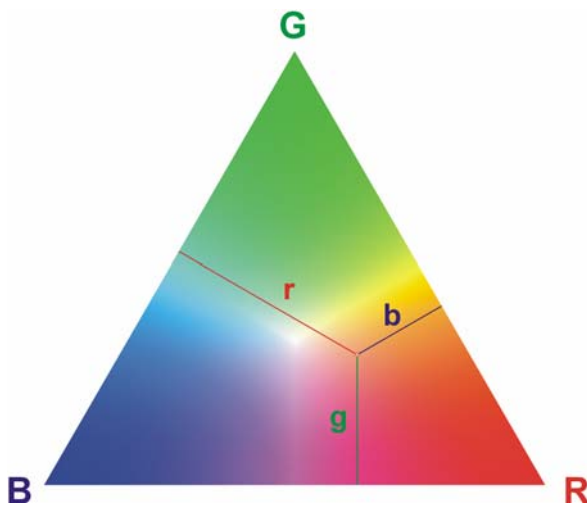

Figure 2. Mixing proper amounts of blue (B) and yellow (Y) lights produces a white (W) light

Line segments r, g and b are perpendicular to GB, BR and RG sides of the equilateral triangle, respectively. The lengths of these line segments represent the quantities of red, green and blue required to produce the colour displayed at the intersection of the segments.

Figure 3. The Maxwell Triangle

Cyan, magenta, yellow and white colours can be produced by the following additive mixtures (Fig. 4):

- Mixing balanced green and blue lights produces a cyan light;
- Mixing balanced blue and red lights produces a magenta light;

- Mixing balanced red and green lights produces a yellow light;
- Mixing balanced red, green and blue lights produces a white light.

Red, green and blue are *additive primary colours*. Each of these colours cannot be produced by any additive mixture of the other two. Cyan, magenta and yellow are *secondary colours*, produced by mixtures of two primary colours. White is a *tertiary colour*, since it is produced by a mixture of all three primary colours. The positions of these seven colours on the Maxwell Triangle are shown on Fig. 5.

2.1. Partitive mixing with coloured disks

Isaac Newton separated white daylight into a sequence of coloured lights divided into seven colour regions, called *Spectrum,* and proposed a diagram such that a rectangular spectrum is bent into a cylinder and then viewed in cross-section [4]. This diagram [5] is known as Newton's Colour Circle (Fig. 6).
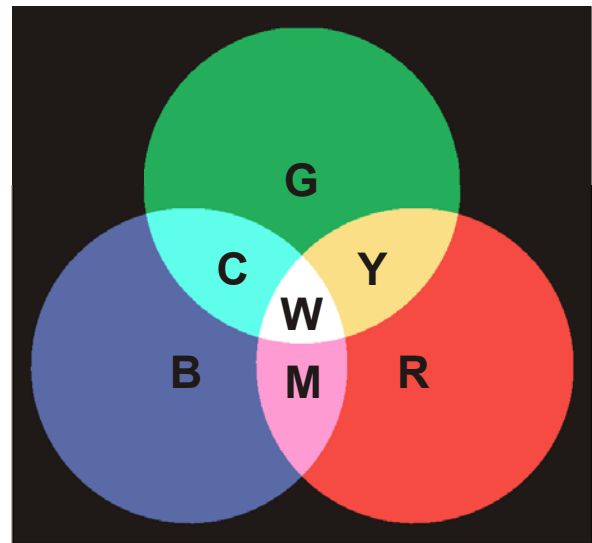

Figure 4. Obtaining cyan (C), magenta (M), yellow (Y) and white (W) lights from mixtures of red (R), green (G) and blue (B) lights

The proof that all the spectral colours could be recombined to form white light is also due to Newton [4]. One approach to accomplish this recombination consists of rapidly rotating a disk containing sectors with the colours existing on Newton's Colour Circle. The device described in this paper has a disk with 7 colours in 14 sectors. It would also be expectable to obtain white by rotating a disk with balanced red, green and blue

_____

sectors (disks with different combinations of red, green and blue sectors are known as *Maxwell disks*). However, rotating disks can only produce greyish white, as will be explained.
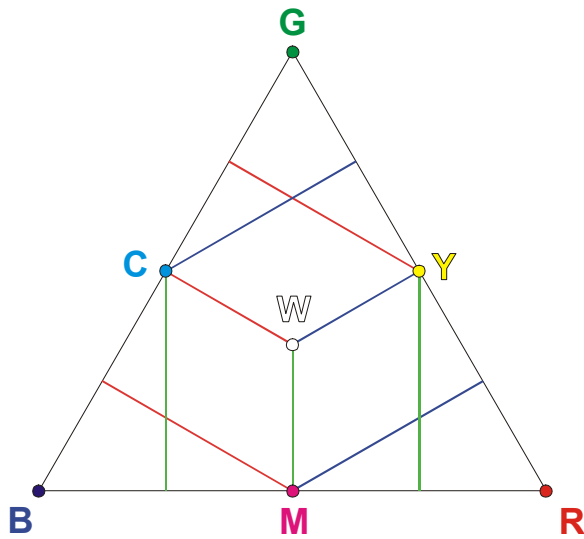

Figure 5. Positions of red (R), green (G), blue (B), cyan (C), magenta (M), yellow (Y) and white (W) colours on the Maxwell Triangle
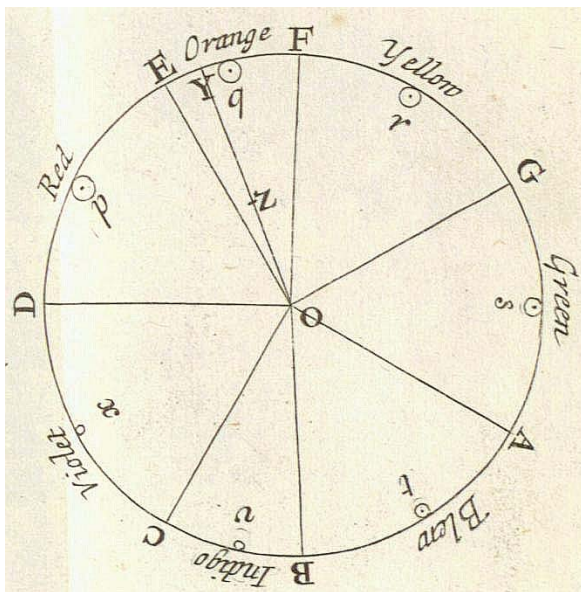

Figure 6. Newton's Colour Circle [5]

Obtaining a colour by rotating a disk with differently coloured sectors belongs to a type of additive mixing of colours known as *partitive mixing*. The amount of each colour in the mixture result is proportional to the sum of the areas of the sectors it occupies in the disk [3, 4]. As a result, the brightness of the mixture is lesser

than the one obtained with simple additive mixing [6].
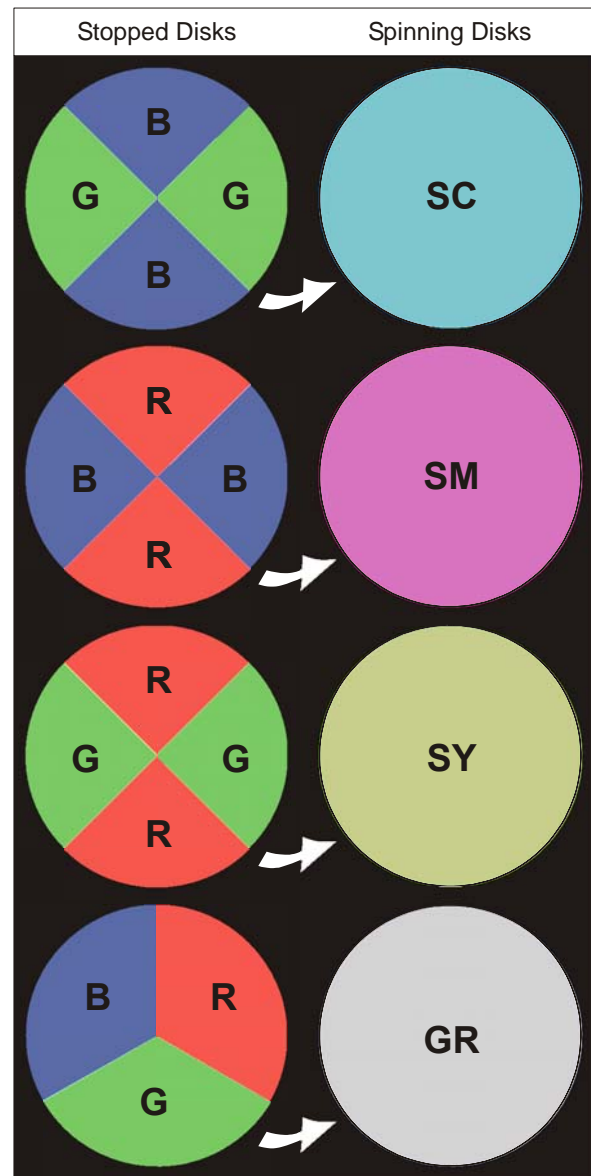

Figure 7. RGB disks coloured sectors configurations and colours obtainable with spinning disks: shady cyan (SC), shady magenta (SM), shady yellow (SY) and grey (GR)

In expressions (1), (2), (3) and (4) below,

- R_{disk}, G_{disk} and B_{disk} are the brightness of red (R), green (G) and blue (B) primaries in the mixtures obtainable using RGB rotating disks with the coloured sectors configurations used in the interactive device (Fig. 7);
- R_{disk}, G_{disk} and B_{disk} are the brightness of red (R), green (G) and blue (B) primaries in each disk surface.

___

$$\text{GB disk} \begin{cases} G_{mixture} = \dfrac{1}{4}G_{disk} + \dfrac{1}{4}G_{disk} = \dfrac{1}{2}G_{disk} \\[2mm] B_{mixture} = \dfrac{1}{4}B_{disk} + \dfrac{1}{4}B_{disk} = \dfrac{1}{2}B_{disk} \end{cases} \quad (1)$$

$$\text{RB disk} \begin{cases} R_{mixture} = \dfrac{1}{4}R_{disk} + \dfrac{1}{4}R_{disk} = \dfrac{1}{2}R_{disk} \\[2mm] B_{mixture} = \dfrac{1}{4}B_{disk} + \dfrac{1}{4}B_{disk} = \dfrac{1}{2}B_{disk} \end{cases} \quad (2)$$

$$\text{RG disk} \begin{cases} R_{mixture} = \dfrac{1}{4}R_{disk} + \dfrac{1}{4}R_{disk} = \dfrac{1}{2}R_{disk} \\[2mm] G_{mixture} = \dfrac{1}{4}G_{disk} + \dfrac{1}{4}G_{disk} = \dfrac{1}{2}G_{disk} \end{cases} \quad (3)$$

$$\text{RGB disk} \begin{cases} R_{mixture} = \dfrac{1}{3}R_{disk} \\[2mm] G_{mixture} = \dfrac{1}{3}G_{disk} \\[2mm] B_{mixture} = \dfrac{1}{3}B_{disk} \end{cases} \quad (4)$$

The brightness of the mixture produced by the tricolour RGB disk is only 1/3 of the brightness obtainable with simple additive mixing of its red, green and blue primaries. Moreover, disks use paints and not light sources. Since mixing paints is a *"subtraction process due to absorption and scattering, the surface becomes less reflective and can give grayish shades only"* [4].

3. Materials used to build the device

The main materials used to build the device were the following:
- 4 metallic disks with RGB sectors (diameter: 10cm) (Fig. 8 and Fig. 9);
- 1 metallic disk with 7 colours in 14 sectors (diameter: 9,7cm) (Fig. 8 and Fig. 9);
- 5 inox push buttons (Fig. 10);
- 5 permanent magnet 3V DC motors (Fig. 11);
- 5 brass adapters (Fig. 12);
- 1 *Bonfil* wooden sketch box with 39cm x 31cm x 7,5cm (Fig. 13);
- 1 DC socket (Fig. 14);
- 1 *HQ* non-regulated 500mA power supply (3V output selected), ref. P.SUP.02-HQ;

- 1 plywood board with 28,5cm x 36,8cm x 1cm.

Other materials include black paint, glue and electric wire.

4. Some details on the device construction and operation

The device has five metallic disks with coloured sectors (Fig. 8). These disks were already described in Section 3. They are activated independently from each other and can rotate all at the same time (Fig. 9).
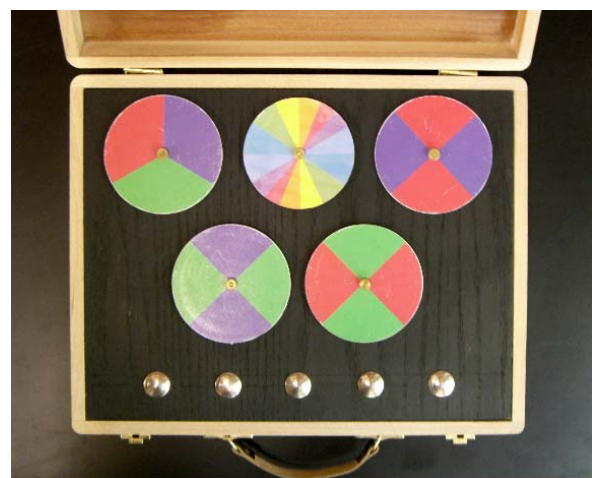

Figure 8. The device has five metallic disks with coloured sectors
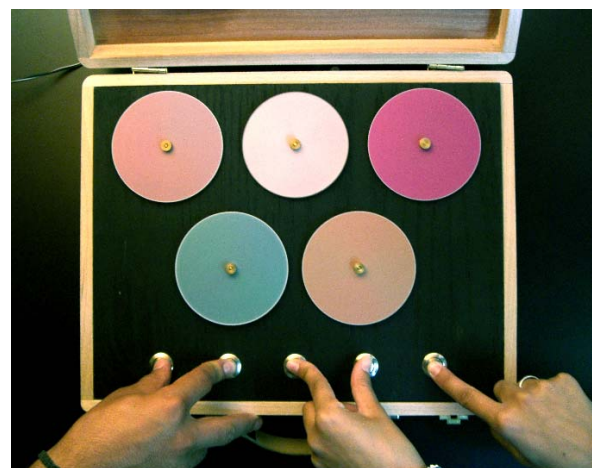

Figure 9. All disks can rotate at the same time

Each disk is set to rotate by pressing a specific push button (Fig. 10), which switches on the DC motor (Fig. 11) attached to the disk. A brass adapter (Fig. 12) was used to attach each disk to its motor.

_____

Ten holes were drilled in a plywood board, in order to hold the DC motors and the push buttons. The board was painted in black before the mounting of the motors and the push buttons. Once the motors and the push buttons were in place, the plywood board was accommodated inside a wooden sketch box (Fig. 13).

A DC socket placed in the rear of the box (Fig. 14) allows an external DC power supply to feed the device.

The schematic of the circuit formed by the power supply, motors and push buttons is shown in Fig. 15.

As expected, the colours obtained with rotating disks have low brightness (Fig. 9). The two-colour GB, RB and RG disks produce dark cyan, dark magenta and dark yellow. The tricolour RGB disk produces a brownish shade and the 7 colours disk produces a pale grey that is a much better approximation to white.
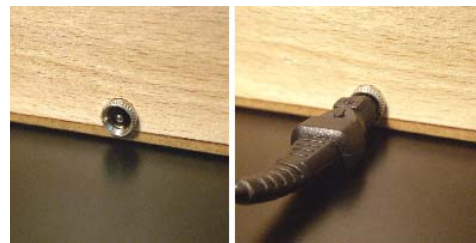

Figure 10. Inox push button

Figure 11. Permanent magnet 3V DC motor

Figure 12. Brass adapter

Figure 13. *Bonfil* wooden sketch box

Figure 14. A DC socket placed in the rear of the box allows an external DC power supply to feed the device
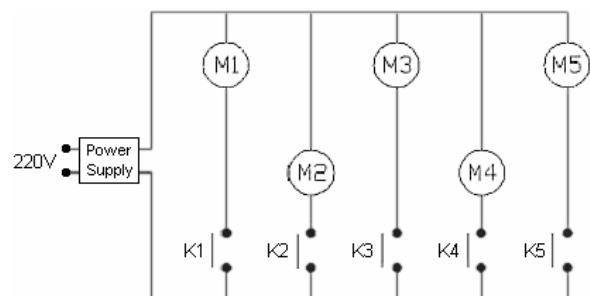

Figure 15. Schematic of the circuit formed by the power supply, motors (M1 – M5) and push buttons (K1 – K5)

5. Conclusions

An interactive device, suitable to demonstrate partitive mixing of colours, has been presented. It uses the following rotating disks:

- Three two-colour, four sectors, RGB disks;
- One tricolour, three sectors, RGB disk;
- One 7 colours, 14 sectors disk.

The device is equipped with five motors that can be switched on individually and each motor holds its own disk. So, more than one disk can rotate at the same time. It is even possible to make all disks rotate at once.

___

Some fundamentals on colour mixing were introduced. A few construction and operation details were given, too.

The colours obtained with rotating disks have low brightness, which is inherent to this way of accomplishing partitive mixing of colours:

- Two-colour RGB disks produce shady cyan, shady magenta and shady yellow;
- The tricolour RGB disk produces a brownish shade;
- The 7 colours disk produces a pale grey that is a much better approximation to white than the colour produced by the tricolour RGB disk.

The device has been successfully used in science exhibitions and in the classroom.

6. Acknowledgements

7. References

[1] McLaren, K.; "The Colour Science of Dyes ad Pigments (2nd ed.)"; Adam Higler Ltd., 1986. ISBN 0-85274-490-0.

[2] McDonald, Roderick; "Colour Physics for Industry"; Society of Dyers and Colourists, 1987. ISBN 0 901956 45 7.

[3] Lucas, J; Valldeperas, J.; Hawkyard, C.; Van Parys, M.; Viallier, P. and Carneiro; N.; "Colour Measurement – Fundamentals (Vol. I)"; Eurotex, 1996.

[4] Choudhury, Asim Kumar Roy; "Modern Concepts of color and appearance"; Science Publishers Inc, ISBN 1-57808-078-9, 2000.

[5] Newton, Isaac; "Opticks: or, A treatise of the reflexions, refractions, inflexions and colours of light. Also two treatises of the species and magnitude of curvilinear figures."; London, Printed for Sam Smith, and Benj. Walford, 1704. http://posner.library.cmu.edu/Posner/books/book.cgi?call=535_N56O_1704 [11/9/2008]

[6] Briggs, David; "Partitive Mixing"; The Dimensions of Colour (online); November 2007. http://huevaluechroma.com/044.php [11/9/2008]