Sound-Colour Synaesthesia, Chromatic Representation of Sounds Waves in Java Applets

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Abstract: –The paper herein presents a way in which sound waves are chromatically represented in Java language. It intends to be, as its' title reveals, an instructional material providing help in developing interactive tools for efficient education in sciences, especially in the field of acoustics. The developed java applets illustrate the main aspects regarding to sound phenomena. It realizes a direct correspondence between visible frequencies of the light and frequencies of sound waves via a sound wave frequency range transformation into a linear scale. The construction of the natural light spectrum was explained in detail, indicating the source code used in applets. Java written software was developed for converting sound wave intensities in colour saturation coefficients. The application allows further development in order to generate a colour visual interpretation of the musical atmosphere and also to develop the performer's creativity. The article addresses the reality in a sensitive manner creating in an undifferentiated manner bridges between face colours and the artistic sensitivity of the human hearing.

Key-Words: - RGB light, Java Applets, sounds waves, music, education

1 Introduction

Knowledge exchange is a very complex process. Although Internet makes the exchange of information possible at high speed rates, knowledge sharing and know-how broadcasting is still an open problem that is waiting for suitable solutions [1]. The new paradigm of active learning can be fostered with the help of e-learning technologies, which take advantage of the familiarity of the students with computers [2]. The sinusoidal time-dependent processes of natural systems are easier to be understood in an interactive way, regarded as a twoway communication process [3].

Most physics systems, including sound and light, seem to have a wave-like behaviour. While light is a transverse electromagnetic wave with an approximately linear scale in the visible region, the sound is an elastic longitudinal wave with a logarithmic frequency scale.

In order to point out the main elements concerning the elastic waves, the computer generation of the light spectrum and the possible correspondence between them, a package of applets embedded in a structure of HTML pages were developed. These applets aim at intuitively revealing the following aspects: the sinusoidal behaviour of a sound wave and the possible association of a corresponding colour to each sound frequency; the principle of obtaining a resulting colour mixture derived from the composition of two sounds, composition of perpendicular oscillations; broadcasting the longitudinal and transversal elastic waves; a visual pattern simulation derived from the composition of elastic waves; stationary waves – Column of air and Vibrating string.

2 Synaesthesia

Synaesthesia (from the Ancient Greek $\sigma \dot{\nu} v$ (syn), "together," and $\alpha \ddot{l} \sigma \theta \eta \sigma \iota \zeta$ (aisthēsis), "sensation") is a neurologically-based condition in which stimulation of one sensory or cognitive pathway leads to automatic, involuntary experiences in a second sensory or cognitive pathway. It represents the involuntary physical experience of a cross-modal linkage — for example, hearing a tone (the inducing stimulus) evokes an additional sensation of seeing a colour (concurrent perception). Of the different types of synaesthesia, most have colour as the concurrent perception, with concurrent perceptions of smell or taste being rare. For example, a musician could experiences different tastes in response to hearing different musical tone intervals, and makes use of his synaesthetic sensations in the complex task of tone-interval identification.

People who report such experiences are known as synaesthetes. Although synaesthesia was the topic of intensive scientific investigation in the late 1800s and early 1900s, it was largely abandoned by scientific research in the mid-20th century, and has only recently been rediscovered by modern researchers. Psychological research has demonstrated that synaesthetic experiences can have measurable behavioural consequences. while functional neuro-imaging studies have identified differences in patterns of brain activation. Many people with synaesthesia use their experiences to aid in their creative process, and many non-synaesthetes have attempted to create works of art that may capture what it is like to experience synaesthesia.

Psychologists and neuroscientists study synaesthesia not only for its inherent interest, but also for the insights it may give into cognitive and perceptual processes that occur in synaesthetes and non-synaesthetes alike.

Richard E. Cytowic is best known for rediscovering synaesthesia in 1980 and returning it to the scientific mainstream. He calls sound \rightarrow color synaesthesia "something like fireworks": voice, music, and assorted environmental sounds such as clattering dishes or dog barks trigger colour and simple shapes that arise, move around, and then fade when the sound stimulus ends. For some, the stimulus type is limited (e.g., music only, or even just a specific musical key); for others, a wide variety of sounds triggers synaesthesia. Sound often changes the perceived hue, brightness, scintillation, and directional movement. Some individuals see music on a "screen" in front of their face.

Of course, mostly people heard about synaesthesia as a figure of speech, which consist in matching two terms that belongs to different sensory modalities (eg. black sound, prickly taste, and so on). Although at school was taught that synaesthesia lives only in the rhetoric world, it does also exist a more concrete dimension of this word, which regards a human perceptive faculty. This phenomenon is quite unusual, but is real, existent. There are people, synaesthetes that can experience indeed sounds as coloured, prickly tastes, coloured graphemes, and much more.

Individuals rarely agree on what colour a given sound is (composers Liszt and Rimsky-Korsakov famously disagreed on the colours of music keys); however, synaesthetes show the same trends as nonsynaesthetes do. For example, both groups say that loud tones are brighter than soft tones and that lower tones are darker than higher tones.

There are several types of synaesthesia, different ways to "perceive together", to experience one external stimulus in different sensory modalities. The present paper focuses on the coloured hearing synaesthesia, and tries to formulate a possible answer to the following questions: can synaesthesia make synaesthetes more creative? Can synaesthesia be appreciated and reproduced also by nonsynaesthetes? And moreover: can synaesthesia be a communication tool?

The investigated field is the one of computers science, software of graphic effects which seems to reproduce exactly the mechanism of the synaesthetic association between hearing and sight, giving also to non-synaesthetic the possibility to live cross-modal connections: *coloured sounds*.

3 Theoretical Aspects

Some theoretical aspects regarding the equation, which describe the physics phenomena and which are implemented in applications, will be briefly presented. The main issues taken into account are the natural light spectrum and its RGB computer simulation, the sinusoidal time dependent representation of a wave and the possible correspondence between a sound and a color. [4], [5].

3.1 RGB generation of natural light spectrum

There are illustrated in Figure 1 the absorption spectra of the four human visual pigments, which display maxima in the expected red, green, and blue regions of the visible light spectrum. When all three types of cone cells are stimulated equally, the light is perceived as being achromatic or white [9]. For example, noon sunlight appears as white light to humans, because it contains approximately equal amounts of red, green, and blue light. Human perception on colours is dependent on the interaction of all receptor cells with the light, and this combination results in nearly tri-chromic stimulation.



Fig.1 Absorption Spectra of Human Visual Pigments

There are shifts in colour sensitivity with variations in light levels, so that blue colours look relatively brighter in dim light and red colours look brighter in bright light. The cone response sensitivities at each wavelength shown as a proportion of the *peak* response, which is set equal to 1.0 on a linear vertical scale, is called Linear Normalized Cone Sensitivities ([7]). This produces the three similar (but not identical) curves shown in figure 2.

This representation is in some respects misleading, because it distorts the functional relationships between light wavelength (energy), cone sensitivity and colour perception. However, the comparison with the absorption curves of the photopigments above identifies some obvious differences between the shape and peak sensitivity of the photopigment and cone fundamentals.

Overall, human eye spectral sensitivity is split into two parts: a short wavelength sensitivity narrow peak centred on "blue violet" (445 nm), and a long wavelength sensitivity broad band centred on about "yellow green" (~560 nm), with a trough of minimum sensitivity in "middle blue" (475 to 485 nm).



Fig. 2 Normalized Cone Sensitivity Functions

3.2 **Free oscillations**

Some physics laws such as: the equation of displacement, the equation of velocity and the equation of acceleration are represented by the following mathematical equations [8]: (1), (2), (3), (4) and (5)

$$y = A * \sin(\omega t + \varphi) \tag{1}$$

$$v = \omega A * \cos(\omega t + \varphi) \tag{2}$$

$$a = -\omega^2 A * \sin(\omega t + \varphi) \tag{3}$$

$$\omega = \sqrt{(\omega_0^2 - \beta^2)} \tag{4}$$

$$A = A_0 e^{-\beta t} \tag{5}$$

where

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- y is the displacement;
- v is the frequency;
- ω is the angular frequency;
- β is the dumping (attenuation) factor;
- A is the amplitude of the oscillation.

3.3 **Composition of parallel oscillations**

Two independent oscillations and the resulting compound motion of these are represented by the equations (6), (7), (8).

a) The equations for the two independent oscillations:

$$y_1 = A_1 * \sin(\omega t_1) \tag{6}$$

$$y_2 = A_2 * \sin(\omega_2 t + \Delta \varphi) \tag{7}$$

b) The equation for the resulting compound motion:

$$y = A_1 * \sin(\omega_1 t) + A_2 * \sin(\omega_2 t + \Delta \varphi)$$
(8)

For the case when the frequencies of the two oscillations are the same, expanding trigonometric function, segregating sine and cosine functions and keeping in mind that $\Delta \phi$ is constant, results in:

$$y = (A_1 + A_2 * \cos(\Delta \varphi)) * \sin(\omega t) + (A_2 * \sin(\Delta \varphi)) * \cos(\omega t) . (9)$$

The expressions in the brackets are constant. Let,

$$C = A_1 + A_2 * \cos(\Delta \varphi)$$
 and $D = A_2 * \sin(\Delta \varphi)$. (10)

Substituting in the expression of displacement, we have: $y = C * \sin(\omega t) + D * \cos(\omega t)$. Following standard analytical method, Let $C = A * \cos(\theta)$ and $D = A * \sin(\theta)$.

Substituting in the expression of displacement again, we have :

$$y = A * \cos(\theta) * \sin(\omega t) + A * \sin(\theta) * \cos(\omega t)$$

$$\Rightarrow y = A * \sin(\omega t + \theta)$$
(11)

This is the final expression of the composition of two simple harmonic motions in the same straight line. Clearly, the amplitude of resulting simple harmonic motion is A. Also, the resulting simple harmonic motion differs in phase with respect to either of the two motions. In particular, the phase of resulting simple harmonic motion differs by an angle θ with respect of first simple harmonic motion, whose displacement is given by $y_1 = A * \sin(\omega t_1)$. We also note that frequency of the resulting motion is same as either of two simple harmonic motions.

The *amplitude* of the resultant harmonic motion is obtained solving substitutions made in the derivation:

$$A = \sqrt{(A_1^2 + A_2^2 + 2A_1A_2\cos\Delta\phi)}$$
(12)

3.4 Mechanical waves

A mechanical wave is a disturbance that propagates through space and time, in an elastic medium (which on deformation is capable of producing elastic restoring forces), usually with transfer of energy.

The harmonic plane wave that propagates on a certain direction OX is described by the equation of propagation (13).

$$\xi(x,t) = A * \cos(\omega t - kx) \tag{13}$$

where:

- ξ is the displacement of the particles of the medium the wave travels in;
- ω is the angular frequency;
- k is the wave number.

For a transverse harmonic wave travelling in the negative x-direction we have:

$$\xi(x,t) = A * \cos(\omega t + kx) \tag{14}$$

A mechanical wave requires an initial energy input to be created. Once this initial energy is added, the wave will travel through the medium until all the energy has been transferred.

Transverse waves are waves that cause the medium to vibrate at a 90-degree angle to the direction of the wave. Two parts of the wave are the crest and the trough. The crest is the highest point of the wave and the trough is the lowest. The wavelength is the distance from crest to crest or from trough to trough.

A *longitudinal wave* is much like a Slinky. When the particles the wave is travelling through are close together, it is called compression. When the particles it is travelling through are spread apart, it is called rarefaction. Another type of heat wave is a abdominal wave. This type of wave is the wave that twists along a given medium. An example would be: if a force twists a coil on one end, and released, the "twist" will travel completely through the wave and end up on the other side.

The *surface wave* travels along a surface that is between two media. An example of a surface wave would be waves in a pool, or in an ocean. Pressure waves travel faster through solids and liquids than through gases such as air. If the vector displacement is perpendicular to the direction the wave travels, the wave is called transversal and if it is parallel to this direction, the wave is called longitudinal.

Sound is transmitted through gases, plasma, and liquids as longitudinal waves, also called compression waves. Through solids, however, it can be transmitted as both longitudinal waves and transverse waves. Longitudinal sound waves are waves of alternating pressure deviations from the equilibrium pressure, causing local regions of compression and rarefaction, while transverse waves (in solids) are waves of alternating shear stress at right angle to the direction of propagation.

Matter in the medium is periodically displaced by a sound wave, and thus oscillates. The energy carried by the sound wave converts back and forth between the potential energy of the extra compression (in case of longitudinal waves) or lateral displacement strain (in case of transverse waves) of the matter and the kinetic energy of the oscillations of the medium.

Sound wave properties and characteristics

Sound waves are characterized by the generic properties of waves, which are frequency, wavelength, period, amplitude, intensity, speed, and direction (sometimes speed and direction are combined as a velocity vector, or wavelength and direction are combined as a wave vector).

3.5 Composition of waves

In physics, *interference* is the addition (superposition) of two or more waves that results in a new wave pattern. Interference usually refers to the interaction of waves that are correlated or coherent with each other, either because they come from the same source or because they have the same or nearly the same frequency.

The principle of superposition of waves states that the resultant displacement at a point is equal to the vector sum of the displacements of different waves at that point. If a crest of a wave meets a crest of another wave at the same point then the crests interfere constructively and the resultant wave amplitude is increased. If a crest of a wave meets a trough of another wave then they interfere destructively, and the overall amplitude is decreased.

This form of interference can occur whenever a wave can propagate from a source to a destination by two or more paths of different length. Two or more sources can only be used to produce interference when there is a fixed phase relation between them, but in this case the interference generated is the same as with a single source.

Huygens–Fresnel principle makes clear the way the waves propagate and can explain the diffraction phenomenon. The propagation of a wave can be described considering every point on a wave front as a point source for a secondary radial wave.

The subsequent propagation and addition of all these radial waves form the new wave front. When waves are added together, the relative phases as well as the amplitudes of the individual waves determine their sum, an effect that is often known as wave interference.





In point B (Fig.3), the wave coming from P is:

$$dy_{\rm B} = \frac{\mu_0}{r} f(\theta) \frac{dS}{r'} \cos 2\pi \left(\frac{t}{T} - \frac{r+r'}{\lambda}\right),\tag{15}$$

where $f(\theta)$ is a function which describes that the amplitudes of the secondary waves are greater for those waves emitted close to the initial direction of the wave and decrease to zero for those emitted under angles with values equal or greater than $\pi/2$ (Fig. 4).

The summed amplitude of the waves can have any value between zero and the sum of the individual amplitudes. Hence, diffraction patterns usually have a series of maxima and minima.



Fig.4 The amplitude function for the light emitted by a secondary source on the wave front

In acoustics, a *beat* is an interference between two sounds of slightly different frequencies, perceived as periodic variations in volume whose rate is the difference between the two frequencies. With tuning instruments that can produce sustained tones, beats can readily be recognized. Tuning two tones to unison will present a peculiar effect: when the two tones are close in pitch but not yet identical, the difference in frequency generates the beating. The volume varies like in a tremolo as the sounds alternately interfere constructively and destructively. When the two tones gradually approach unison, the beating slows down and disappears, giving way to full-bodied unison resonance.

This phenomenon manifests acoustically. If a graph is drawn to show the function corresponding to the total sound of two strings, it can be seen that maxima and minima are no longer constant as when a pure note is played, but change over time: when the two waves are nearly 180 degrees out of phase the maxima of each cancel the minima of the other, whereas when they are nearly in phase their maxima sum up, raising the perceived volume.

It can be proven that the successive values of maxima and minima form a wave whose frequency

equals the difference between the two starting waves:

$$\sin(\omega_1 t) + \sin(\omega_2 t) = 2\cos(\frac{\omega_1 - \omega_2}{2}t) * \sin(\frac{\omega_1 + \omega_2}{2}t)$$

If the two starting frequencies are quite close (usually differences of the order of few hertz), the frequency of the cosine of the right side of the expression above, that is $(\omega_1 - \omega_2)/2$, is often too slow to be perceived as a pitch. Instead, it is perceived as a periodic variation of the sine in the expression above (it can be said, the cosine factor is an *envelope* for the sine wave), whose frequency is $(\omega_1 + \omega_2)/2$, that is, the average of the two frequencies. However, because the sine part of the right side function alternates between negative and positive values many times during one period of the cosine part, only the absolute value of the envelope is relevant. Therefore the frequency of the envelope is twice the frequency of the cosine, which means the beat frequency is: $\omega_{beat} = \omega_1 - \omega_2$.

A physical interpretation is that when $\cos(\frac{\omega_1 - \omega_2}{2}t)$

equals one, the two waves are in phase and they interfere constructively. When it is zero, they are out of phase and interfere destructively. Beats occur also in more complex sounds, or in sounds of different volumes, though calculating them mathematically is not so easy.

Beating can also be heard between notes that are near to, but not exactly, a harmonic interval, due to some harmonic of the first note beating with a harmonic of the second note. For example, in the case of perfect fifth, the third harmonic (i.e. second overtone) of the bass note beats with the second harmonic (first overtone) of the other note. As well as with out-of tune notes, this can also happen with some correctly tuned equal temperament intervals, because of the differences between them and the corresponding just intonation intervals.

Difference tones

Consider the two waves starting in unison, $\omega_1 - \omega_2 = 0$. As the difference between ω_1 and ω_2 increases, the speed increases. Beyond a certain proximity (about 15 Hz), beating becomes undetectable and a roughness is heard instead, after which the two pitches are perceived as separate. If the beating frequency rises to the point that the envelope becomes audible (usually, much more than 20 Hz), it is called a difference tone.

The violinist Giuseppe Tartini was the first to describe it, dubbing it *il Terzo Suono* (Italian for

"the third sound"). Playing pure harmonies (i.e., a frequency pair of a simple proportional relation, like 4/5 or 5/6, as in just intonation major and minor third respectively) on the two upper strings, such as the C above middle C against an open E-string, will produce a clearly audible C two octaves lower. Musicians commonly use interference beats to objectively check tuning at the unison, perfect fifth, or other simple harmonic intervals. Piano and organ tuners even use a method involving counting beats, aiming at a particular number for a specific interval. The composer Alvin Lucier has written many pieces which feature interference beats as their main focus. Italian composer Giacinto Scelsi, whose mature style is grounded on microtonal oscillations of unisons, extensively explored the textural effects of interference beats, particularly in his late works such as the violin solos Xnovbis (1964) and L'âme ailée / L'âme ouverte (1973), which feature them prominently.

In order to simulate the composition of mechanical plane waves a number of four waves were taken into account, a longitudinal and a transversal wave for each of the two main directions - vertical and horizontal. For each of these waves the frequency and the amplitude can be modified.

3.6 Stationary (standing) waves

A standing wave, also known as a stationary wave, is a wave that remains in a constant position. This phenomenon can arise in a stationary medium as a result of the interference between two waves travelling in opposite directions. In this case, for waves of equal amplitude travelling in opposing directions, there is on average no net propagation of energy.

The effect is a series of nodes (zero displacement) and anti-nodes (maximum displacement) at fixed points along the transmission line. Such a standing wave may be formed when a wave is transmitted towards one end of a transmission line and is reflected from the other end.

Harmonic waves traveling in opposite directions can be represented by the equations below:

$$\xi_1(x,t) = A * \cos(\omega t - kx) \text{ and}$$

$$\xi_2(x,t) = A * \cos(\omega t + kx)$$

where:

- *A* is the amplitude of the wave,

- ω (called angular frequency, measured in radians per second) is 2π times the frequency (in hertz).
- k (called the wave number and measured in _ *radians per metre*) is 2π divided by the wavelength λ (in *metres*), and
- x and t are variables for longitudinal position and time, respectively.

So the resultant wave ξ equation will be the sum of ξ_1 and ξ_2 :

$$\xi = A * \cos(\omega t - kx) + A * \cos(\omega t + kx).$$
⁽¹⁶⁾

Using a trigonometric identity to simplify:

$$\xi = 2A * \cos(\omega t) * \cos(kx). \tag{17}$$

This describes a wave that oscillates in time, but has a spatial dependence that is stationary: cos(kx). At locations $x = 0, \lambda/2, \lambda, 3\lambda/2, \dots$ called the *nodes*, the amplitude is always zero, whereas at locations x = $\lambda/4$, $3\lambda/4$, $5\lambda/4$, ... called the *anti-nodes*, the amplitude is maximum. The distance between two conjugative nodes or anti-nodes is $\lambda/2$.

Standing waves can also occur in two- or threedimensional resonators. With standing waves on two dimensional membranes such as drumheads, the nodes become nodal lines, lines on the surface at which there is no movement, that separate regions vibrating with opposite phase. These nodal line patterns are called Chladni figures. In threedimensional resonators, such as musical instrument sound boxes there are nodal surfaces.

Two waves with the same frequency, wavelength and amplitude travelling to opposite directions will interfere and produce a standing wave or stationary wave. The general equation of a standing wave is represented as follows (18).

$$\xi(x,t) = 2 * A * \cos(\frac{2\pi x}{\lambda} + \frac{\pi}{2}) * \sin(\omega t - \varphi) \quad (18)$$

A standing wave is the vibration state of a coherent system. As an example for this usually the vibrating string of a musical instrument or the column of air in an organ pipe is taken. These waves have a wavelike look, but nothing is moving. The string is clamped with a length L between two *fixed ends*, which is always a node. Between two nodes is always an antinode. The frequencies of the vibrations form *harmonics*, also called *partials*.

The room resonances formed between the boundary surfaces of a room, are called "standing waves" or room modes, or modes. They arise if a multiple of half

the wavelength $(\lambda/2)$ fits between the boundary surfaces of an area. Therefore, one need not necessarily parallel walls. Sound technicians are interested in the behavior of the sound pressure, because by its effect our eardrums and the microphone diaphragms are moved.

4 "Coloured Sounds" application

"Coloured Sounds" application is written in Java and reveals a chromatic representation suggestion of sounds by associating a corresponding light frequency to each elementary sound frequency. Furthermore, the intensity of the sound is revealed in the application by a properly adapted value of the colour saturation. The set of applets intuitively reveals the following aspects: the sinusoidal behaviour of a sound wave and the possible association of a corresponding colour to each sound frequency; the principle of obtaining a resulting colour mixture derived from the composition of two sounds, composition of perpendicular oscillations; broadcasting the longitudinal and transversal elastic waves; a visual pattern simulation derived from the composition of elastic waves; stationary waves -Column of air and Vibrating string

4.1 Simulation of RGB generation of natural light spectrum

For the generation of the natural light spectrum, the proposed functions for the three components (RGB) are presented in Fig. 5, functions which lead to the spectrum shown in Fig. 7.



Fig.5 Linear functions for simulating the RGB generation of the natural light.

These functions were defined in a java **public class Light** (Fig. 6) [9], as *Light.color* (int. *wavelength*), function which returns the appropriate colour associated to the value of the wavelength argument.

```
public class Light {
public Color color (int wl) {
Color color=new Color(R(wl), G(wl), B(wl));
return color; }
public int R(int wl) {
                           int r=255;
if (w1>750)
                     r=0;
else if (wl>700)
                     r=(int)(255*(800-wl)/100);
else if (wl>550)
                     r=255;
else if (wl>500)
                     r=(int)(255*(w1-500)/50);
else if (wl>425)
                     r=0:
else if (wl>400)
                     r=(int)(255*(425-wl)/50);
else if (wl>350)
                     r=(int)(255/2);
else
                     r=0;
return r;
            }
public int G(int wl) {
                           int g=255;
if (w1>650)
                    q=0;
else if (wl>550)
                     g=(int)(255*(650-wl)/100);
else if (wl>500)
                     q=255;
else if (wl>450)
                     g=(int)(255*(w1-450)/ 50);
else
                     q=0;
return g; }
public int B(int wl){
                            int b=255;
if (w1>525)
                     b=0;
else if (wl>450)
                     b=(int)(255*(525-wl)/75);
else if (wl>400)
                     b=255;
else if (wl>350)
                     b=(int)(255*(w1-300)/100);
                     b=0;
else
return b;
           }}.
```

Fig.6. Java-source code for public class Light



4.2. "The colour of the sound" application

The application presents the time-dependent representation of a sinusoidal oscillation (sound source) allowing adjustments to be made for the frequency and the amplitude. In the lower region of the application panel (Fig. 8) the background of a defined window changes its colour according to the frequency and amplitude of the sound. The frequency spectrum of sound waves has a logarithmic scale between the extreme values 20 Hz -20 kHz while the visible spectrum of light is bounded by the highest wavelength value of 750 nm for red and the lowest wavelength value of 350 nm for violet. By transforming the sound frequencies scale into a linear one, a direct correspondence between the two frequency spectra was established so that the high wavelength light colours (red, orange, yellow) were associated to low frequency sounds and low wavelength light colours (green, blue, violet) were associated to high frequency sounds.



Fig.8 "The colour of the sound" application

The application has the following three buttons: "Reset", "Trace" and "Stop/Start". By activating the "Trace" option, the time-dependent movement of a sound source is recorded, simulating the wave broadcasting. The "Reset" option allows actualizing the starting moment for trace registering. The frequency and amplitude of the simulation may be changed at any time using the two sliders placed in the upper right side of the applet.

4.3 "Mixture of two Sounds" applications

"Mixture of two Sounds" application is created to the purpose of visualising the resulting colour mixture derived from the composition of two sounds (Fig. 9). Mention should be made that combining two sounds does not result in a simple overlapping of the two corresponding colours but in a constructive/destructive composing process both for the intensity and the chromatic range. In Fig. 9, four strips are visible in the designated colour panel.

The two external strips stand for the colours associated with the elementary sounds while the two inner strips reveal the resulting composed colours which partly cover the previous with a transparency coefficient "*alpha*", calculated to be proportional with the two elementary amplitudes and frequencies.

Equation (19) reveals the way the transparency coefficient "alpha" is computed:

$$alpha = |(\mathbf{A}_1 + \mathbf{A}_2) \cdot \cos(k \cdot \pi \cdot t \cdot (\nu_1 - \nu_2))|$$
(19)

where:

- A_1 , A_2 represent the amplitudes of the sounds;
- v_1, v_2 represent the frequencies of the sounds;



Fig. 9 "Mixture of two Sounds" application

The amplitude and the frequency for each of the two oscillations can be modified using the corresponding sliders.

4.4 "Mechanical Waves" application

The panel shown in Fig. 10 is built for the *Mechanical Waves* application. This application simulates the propagation of a longitudinal and a transversal elastic wave offering the possibility to modify the amplitude and the frequency (angular frequency) for each wave. Using a Checkbox one may reverse the direction of propagation transforming a progressive wave into a regressive one.



Fig. 10 Mechanical Waves application

A window was included in the right side of the screen of the applet. In this window, the particles of the medium wherein the wave travels can be freely reshaped (using the "ZOOM" option) and the interactions between them are simulated using connecting springs which are distorted during the wave propagation. The simulation is presented both for a transversal and for a longitudinal wave.

The frequency and amplitude of the wave can be modified by choosing the desired position on the scroll bar.

4.5 "Composition of Waves" application

The panel standing for *Composition of Waves* application is the one presented in Fig. 11.

The application allows the visualization of the particles of the medium the wave travels in (using the "ZOOM" option) and the apparent motion of the medium as a visual pattern derived from the composition of elastic waves. In order to be presented in a suggestive way, the medium fragments were coloured according to the oscillation direction and the value of the wave vector.



Fig. 11 Composition of Waves application

In the window included in the left side of the applet, the motion of the particles of the medium wherein the superposition of waves travels is simulated. By choosing the desired position on the scroll bar (using the "ZOOM" option) the particles of the medium change their size. The frequency and amplitude of each wave can be modified using the scroll bars "*Amplitude*" and "*Frequency*".

4.6 "Stationary Waves" application

The page shown in Fig. 12 is built for the *Stationary waves* application.



Fig. 12 Stationary Waves application

The application shows both Column of air and Vibrating string case. Increasing the frequency leads to different oscillation modes. Consecutively a standing wave is created, allowing harmonics to be identified. The column of air can be regarded as with a closed or opened end on both sides using the appropriate Checkbox.

5 Conclusion

The application is fully interactive, allowing the student to study in a playful way. The visual support allows a better understanding of the phenomena, transforming hours of explanations in just a few minutes. The animations and the possibility to review them allow the student to provide optimum feedback to the teacher. Therefore, the teacher has a useful instrument, which completes the classical teaching methods. The virtual experiments not only allow a better description of the phenomena, but also allow the modification of the parameters of the sound introducing a different way of its perception and representation.

The present paper can be further developed using a Fourier decomposition of musical signals and combining their corresponding colours in a characteristic visual image. Thus, a visual picture of musical compositions can be achieved. This picture can still be used in creating a psychologically comfortable atmosphere, as a desired effect of a visual image on the human body, ranging up to a physical therapy through music and colours. Of course, the desired effects are to be further investigated. The idea developed in this paper may have important educational valences by stimulating the interest for sounds and colours and by widening the reality perception area. On the other hand, the application developed in this manner can be successfully used in the e-Learning and distance Learning systems for the benefit of pupils and students. Being a Java based application it can be also easily integrated in web pages.

The idea of using applets as a teaching tool, both in face-to-face and online learning, is quite extended. The content of the lecture does not change, but the methods intend to improve the students' attitude towards active learning [10]. The best option is to use graphical and interactive tools in two ways. On one hand, these tools help the teacher in the classroom; while on the other hand, the students can work and experiment making their own examples, outside the classroom [11].

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