An Interactive Concert Program Based on Infrared Watermark and Audio Synthesis

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Abstract. The objective of this research is to propose a video/audio system which allows the user to listen the typical music notes in the concert program under infrared detection. The system synthesizes audio with different pitches and tempi in accordance with the encoded data in a 2-D barcode embedded in the infrared watermark. The digital halftoning technique has been used to fabricate the infrared watermark composed of halftone dots by both amplitude modulation (AM) and frequency modulation (FM). The results show that this interactive system successfully recognizes the barcode and synthesizes audio under infrared detection of a concert program which is also valid for human observation of the contents. This interactive video/audio system has greatly expanded the capability of the printout paper to audio display and also has many potential value-added applications.

Keywords: Data hiding, 2D barcode, digital image processing, halftoning.

1 Introduction

For more than a thousand years, paper has been esteemed as the most popular interface [1] between human and information, like texts, graphics and music notes. As the advance of digital technology, a major part of information carrier has been shifted to internet and disk storage. However, most people still enjoy reading printed books/newspapers/magazine in a traditional way. In this research, the printed concert program is designed for both human vision of the printed texts/graphics contents under visible light and computer vision of embedded musical scores under infrared detection. Then, the concert program is not just a 2D printed medium but also an interactive interface to play some typical music notes in the concert. Some techniques involved in this printed concert program are reviewed in the following subsections.

1.1 Digital Halftoning Technique

Halftoning is a traditional printing process. Due to the limited tone which the output device can provide, a con-tone image has to be halftoned or binarized before it can be actually output. Since human eyes have the ability to integrate the neighboring halftone

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dots, the output binary image is perceived like a continuous tone image. With the fast innovation of computer technology, digital halftoning technique [2] is adopted by nowadays printing industry and desktop printers. In general, methods of digital halftoning fall into one of two categories: amplitude modulation (AM) and frequency modulation (FM), shown in Fig. 1.

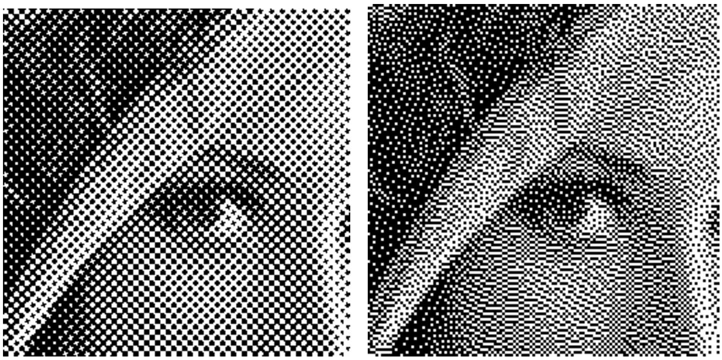


Fig. 1. Typical halftone images. Left: Amplitude modulation (AM), and Right: Frequency modulation (FM).

The amplitude modulation is also known as ordered dithering, and the smallest individually printed halftone dots form a regular pattern in Fig. 1(a). The original gray-scale image is divided into many 8x8 or other sized blocks to compare with the entries in the threshold matrix and to complete the binarization. On the other hand, the frequency modulation screening by error diffusion (shown in Fig. 1(b)) takes a totally different approach to generate a binary image for reproducing a continuous tone image. Although the computational complexity is higher for error diffusion, frequency modulation can provide better spatial resolution of the details.

1.2 Digital Watermarking in Printed Medium

With rapid development of modern computer technology, multimedia and network, researches on information hiding in image, audio and other media have attracted lots of researchers [3,4], including at MIT Media Lab. Due to limited depth for hiding information, data hiding in bi-level image is considered much more challenging and less addressed in the related research fields. However, data hiding in bi-level image is indeed on demand because printing and some display systems are in bi-level. Most of all, data hiding especially has great potential in security document printing, and may significantly help to strike counterfeiting and illegally duplicating. Works have reported several document protection schemes to modify the digital halftoning processes and to obtain deformed or shifted halftone dots to encode the hidden data [5,6]. Wang et al. [7] also blend the AM/FM halftone dots to an anti-copy security printed image and invisible marker design for augmented reality (AR). By careful manipulation of the formation of halftone dots, various applications to obtain secured document can be derived. It is the key technology to link the computer digital world and printed physical document.

1.3 The Characteristics of Inks under Infrared

Carbon black, which consists of pure element of carbon, is known as a common black pigment. Modern ink-jet printer uses it as the major presentation of black (K) ink. Carbon appears dark because it absorbs almost all wavelength of light from ultraviolet to infrared of the spectrum. In contrast, inks of cyan (C), magenta (M) and yellow (Y) absorb much less infrared light. The transmission percentage for each ink at different wavelength is shown in Fig. 2.

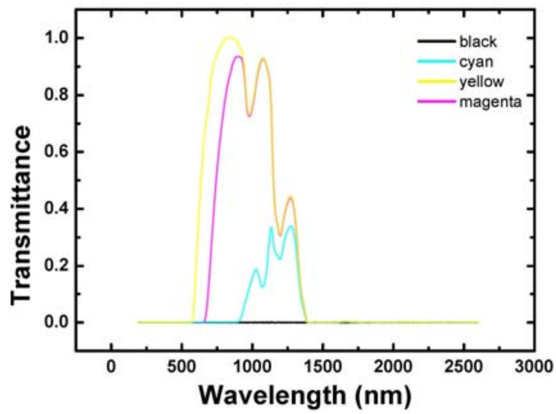


Fig. 2. The transmission percentage for each ink

There are some specially-manufactured fluorescent/infrared inks which can display distinct difference under visible light and infrared light [8]. With carefully manipulating the CMYK halftone dot distribution, watermark can be hidden in a printed image without involving special material. By using of the optical characteristic of carbon black, ImageSwitch was proposed by researchers in Japan [9]. It's not only using the digital watermark but also using the irregular shaped cell to allocate the CMYK halftone dots. The hidden pattern or watermark can be observed under the infrared illumination.

2 Methods

This research combines audio/image processing, watermark embedding, image capture and content design. The multi-disciplinary feature especially fits quite well with the recent development of the integration of technology and art.

The equipment used in this study is listed in Table 1. No special material, such as fluorescent ink, is involved. Desktop PC and printer can serve as the core tools to obtain the infrared watermark.

Table 1. Equipment used in this study.

Devices	Desktop PC
	HP DeskJet 1280 inkjet printer
	Infrared webcam
	PerkinElmer Lambda 900 spectrometer
	X-Loupe Portable Microscope Camera from Lumos Technology
Tools	Matlab 2007a (Programming Language Software)
	Adobe Illustrator (Graphics Software)
	Adobe Photoshop (Image Software)

2.1 Music Data Encoding

The music scores (shown in Fig. 3) are originally composed by Professor Wen-Pin Lee, the coauthor of this paper. The first 8 notes are selected to encode a 2-D barcode to be hidden in the concert program. Eight bits are used to encode one music note. Six of the eight bits are for pitch, and the other 2 bits are for the duration (rhythm), respectively. There are 64 bits in total encoded. Finally, the 64 ones and zeros is randomized and reshaped as an 8x8 square matrix which is shown in Fig. 4. Four black brackets are added to the 2-D barcode to provide the ability to register the input image. In the following procedures, this 2-D barcode is processed as a 12x12 binary square matrix. Though only the central part of the binary image sized 8x8 is the embedded music information.

Fig. 3. The original notes, scored by Prof. Wen-Pin Lee, are to be embedded in the watermark of concert program

Fig. 4. The 2-D barcode contains the music notes

2.2 Design of the Infrared Watermark

Since different multimedia elements, like texts, image, graphics, video and audio, are integrated in the digital era, the concert program in this research is also carefully designed. It is essential that the concert program be both aesthetically pleasing and practically designed for its end application [10]. A painting is chosen as the cover image of infrared watermark. In order to make the hidden watermark invisible, some procedures have to be adopted. The composition of AM (S_2) halftone image and FM (S_1) halftone image is carried out by using a binary mask, M. The composed watermark image, S_A, can be obtained according to Equation (1).

$$S_A(\mathrm{i,j}) = S_1(\mathrm{i,j}) \cdot M(\mathrm{i,j}) + S_2(\mathrm{i,j}) \cdot \sim M(\mathrm{i,j}) \quad (1)$$

The close-up microscopic image of the composed AM halftone dots (ink of black, K) and FM halftone dots (inks of C, M, Y) is shown in Fig. 5. At a normal viewing distance (30cm), density of black ink and density of the combination of CMY inks will be balanced. Due to the different dot gain of AM and FM halftone dots, a calibration chart is designed to get the optimum output parameters. That is, the watermark will achieve the best hidden effect for human perception.

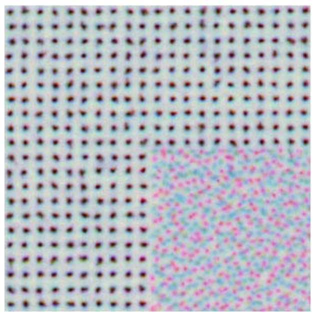


Fig. 5. The micro-structure of the AM halftone dots (ink of black, K) and FM halftone dots (inks of C, M, Y)

2.3 Audio Synthesis and System Installation

The synthetic audio signals are based on the fundamental frequency. The sinusoidal waveform is generated according to Equation (2). [11]

$$y(\mathrm{t}) = A \sin 2\pi f\, \mathrm{t} \quad (2)$$

where A is the signal amplitude, f is the musical note's frequency (in Hz) and t is time (in second). In discrete format, t can be represented as $m\Delta$t, where m is an integer (or number of samples) and Δt is the sampling period which is represented in Equation (3).

$$\Delta \mathrm{t} = 1 / f_s \quad (3)$$

where f_s is the sampling frequency (in Hz). In general, sound is composed of sine waves and cosine waves, and its waveform is very complex. During the synthesis of audio signal in this study, the sinusoidal wave based on the fundamental frequency generates the fork's timbre. In this study, the synthesized waveforms at sampling rate of 11025 Hz are used.

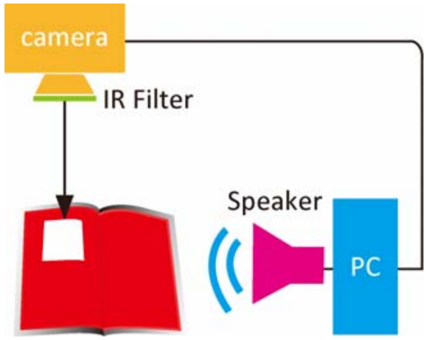
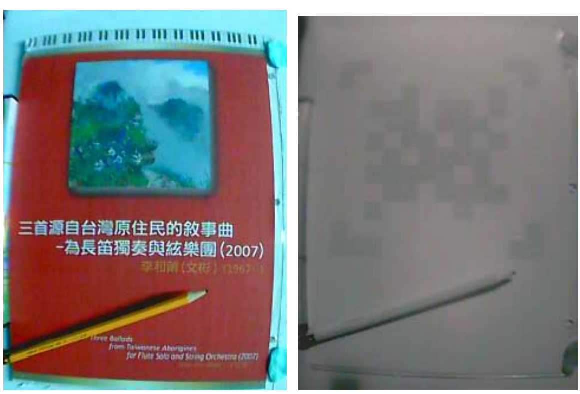


Fig. 6. The schematic diagram of experimental setup

The schematic diagram of the interactive system is illustrated in Fig. 6. It can demonstrate that an image is captured by web camera, and the data in the 2D barcode is recognized as music scores. Then the audio is synthesized and the system can play the encoded audio signals. It should be noted that, the IR filter in Fig. 6 is to block up the visible light and to let the invisible IR light pass through the filter. The CCD/CMOS has the IR detection ability in near IR range.

3 Results and Discussion

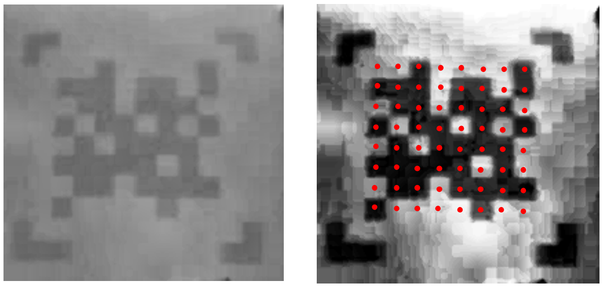
The designed concert program in this research displays very different scenes by human observation and infrared detection (shown in Fig. 7). The watermark hidden in the cover image of a painting is visible under IR detection. However, the signal of watermark is not strong enough and is subjected to various noise attacks. In Fig. 8(a), the portion of the 2D barcode has further been enhanced by adaptive histogram



(a) (b)

Fig. 7. The designed concert program shows distinct features by human observation and computer vision. (a) under visible light. (b) under infrared detection.

equalization to eliminate the non-uniform lighting. By digital image processing techniques, including geometrical transformation and image registration (the red points in Fig. 8(b)), the music data in the 2-D barcode is detected and recognized. The audio waveforms are synthesized according to decoded data in 2D barcode. The first 4 notes with frequency of 392Hz, 294Hz, 494Hz and 392Hz at sampling frequency of 11025Hz are illustrated in Fig. 9. The x-axis is the number of the samples and the y-axis is the signal amplitude. It shows that these waveforms have very different fundamental frequencies.



(a) (b)

Fig. 8. (a) The close-up image of the infrared watermark. (b) The image analysis of the notes embedded in the 2D barcode.

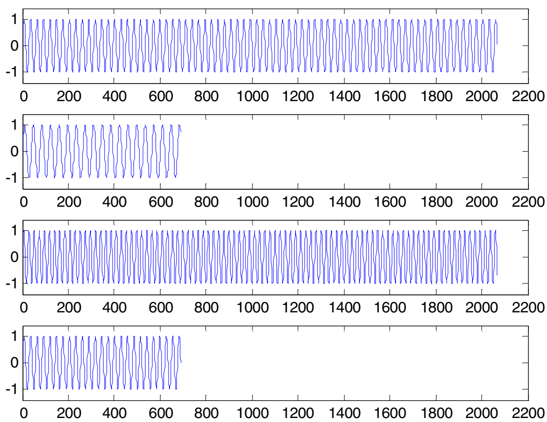


Fig. 9. The synthesized waveforms for the first 4 notes with frequency of 392Hz, 294Hz, 494Hz and 392Hz at sampling frequency of 11025Hz

4 Conclusions

The results of this research show that the proposed concert program is successfully implemented for both human vision of the printed texts/graphics contents under visible light and computer vision of embedded musical scores under infrared detection. This interactive video/audio system has greatly expanded the capability of the printout paper to audio display and also has many potential applications to interactive art, e-learning, game development and anti-counterfeiting technology. In the future works, the system will be fine-tuned to synthesize higher quality audio sound by MIDI format or by newly developed IEEE 1599 music encoding standard for interactive application [12]. The pattern recognition technique will be used in this system to automatically extract the control points and let the user to use the mobile device such as camera phone to perform the interactive audio/video system.

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