Music Score Watermarking

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INTRODUCTION

Music publishers, authors and/or distributors have high quantity of music scores in their archives. In classical music, the original music piece is normally kept in paper format, since its production goes back to many years ago. At present, only new light and popular music pieces are in symbolic notation formats. Light and popular music have a limited lifetime when compared with classical music pieces. The duration of the copyrights for that kind of music is about 60-80 years. Content owners are very cautious to transform their classical music pieces in digital format for e-commerce purposes, because they consider it as a highly risky process which could ultimately lose their copyright ownership. The situation is different when it comes to light and popular music, being market life shorter. According to content owners' opinion, e-commerce for music distribution cannot be accepted, unless adequate protection mechanisms are provided, as highlighted in WEDELMUSIC (www.wedelmusic.org) and MUSICNETWORK (www.interactivemusicnetwork.org). They accept to have their music protected only if it is possible to control while at the same time the users exploit content functionalities according to the established permissions and prices. To cope with these problems, mechanisms for protecting digital musical objects are used (see Table 1).

In this article, only problems and solutions for protecting and watermarking music scores are discussed.

Most music scores are still kept in paper format at publisher's archives. A first step to transform them into digital documents can be transforming them into images with a scanner. Another possible solution can be found in transforming them manually into symbolic music with a music editor. Obviously, this latter solution is very expensive, since the music has to be totally retyped. The use of very efficient Optical Music Recognition (OMR) software, similar to the Optical Character Recognition (OCR), seems to be quite unlikely in the next future. Currently, their recognition rate is close only to 90%, which makes this approach not too much reasonable when compared with retyping (www.interactivemusicnetwork.org, see assessment on the Working Group of Music Imaging).

Music images or symbolic music are obtained after music sheet digitalization. In the event of images, no further music manipulation is possible at the level of symbols. On the other hand, images can be easily viewed in any operating systems and with plenty of applications. The symbolic music gives several advantages in the score maintenance and manipulation; it allows the user to perform changes on the music, such as to justify it, change the page settings, add ornaments, accents, expressions, view single parts or the whole score, and so forth. The drawback consists in all these possible operations being performed only if the music editor is available: professional music sheets are produced by expensive and professional music editors.

It is well known that music sheets are distributed in paper format among musicians. Therefore, it seems that such digitizing process is useless. Practically speaking, Internet music sheet distribution, meaning from publishers to consumers, can only be achieved using digital formats. Distribution among users, as it occurs now with photocopies, could be made even via digital music sheets, as Napster did with audio files. Please note that on P2P (peer to peer) application there is also a quite significant distribution of music scores (www.interactivemusicnetwork.org, read report on Music

Table 1: Mechanisms for protecting digital musical objects

- encryption techniques to support any transferring of music objects;
- watermarking audio files in different formats;
- watermarking images of music score sheets;
- watermarking music sheets while they are printed from symbolic notation files.
- definition of digital rights management policies.

Distribution Models of the Working Group on Music distribution).

Whenever using digital formats, music could be converted again into paper (today musicians play music only from paper sheets).

BACKGROUND

The most relevant features for algorithms of score watermarking can be summed up into three categories (Monsignori, Nesi, & Spinu, 2003):

Content Requirements:

- The embedded data may contain a simple identification code, which allows to recover the publisher and the distribution IDs simply by consulting a Web service. To this end, hiding about 100 bits is typically enough. The code can be encrypted, compressed and may include control and redundant bits to increase robustness.

Visual Requirements:

- The watermark inserted in the printed music sheet has to be invisible for musicians or at least it should not bother musicians during their execution.
- The watermark has to be included in the music printed by the final user in any format if the music is available in symbolic format. Therefore, the watermark reading has not to depend on the availability of the original reference image of the music sheet.

Resistance Requirements:

- The cost to remove watermark must be extremely expensive when compared to any regular purchase of the same music sheet.
- The watermark must resist against music sheet manipulation until the music printed becomes unreadable. Typically, five levels of photocopy are enough to make music unreadable or of a very bad quality.
- The watermark has to be readable when processing each single page or smaller part.

In addition, there are other parameters to be taken into account in order to analyze the technique capability.

- The amount of embedded information has a direct influence on watermark robustness. Typically, the hidden code is repeated several times in the same page; therefore, the bigger is the code, the lower is the number of times such code can be repeated, which means a decrease in the general robustness.
- Embedding strength " There is a trade-off between watermark embedding robustness and quality. Increased robustness requires a massive embedding of hidden bits. This increases music score degradation and watermark visibility.

Please note that watermarking images of scores or watermarking symbolic music lead to the same result: a watermarked music sheet. The watermarked music (symbolic or image) should be kept in some unchangeable digital file formats (like PDF) or in some formats difficult to change (PostScript), image format. The implementations of the algorithms for music watermarking in such two events are completely different (Busch, Nesi, Schmucker, & Spinu, 2002). In the first event, the watermarking is performed while the music score is printed by manipulating graphic primitives such as lines, music fonts, and so forth, and the process may generate a PostScript file or may send the information directly to the printer. In the latter case, the watermarking is performed by manipulating the B/W images.

In order to read the watermarked hidden code, the music sheet has to be scanned and the resulted image has to be elaborated with the watermark reader, to reconstruct the embedded code. The main advantages of distributing symbolic music sheets, instead of images are:

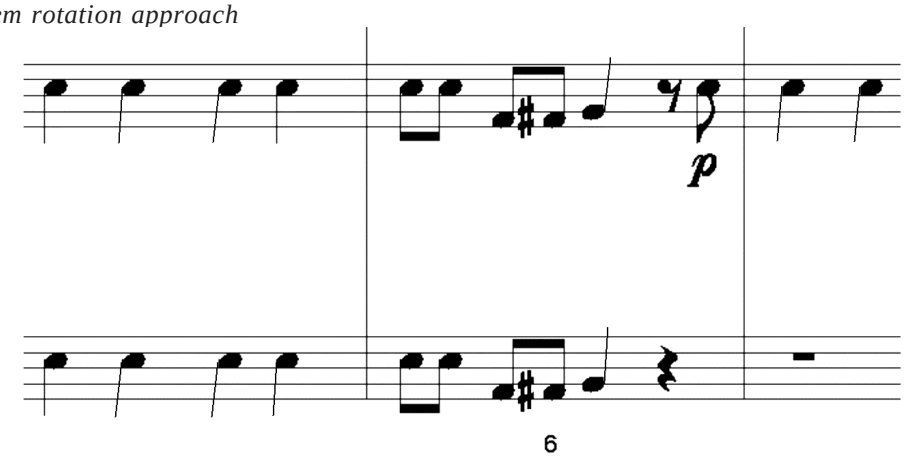
- Lower number of bytes for coding music, easier distribution, lower costs of download, and so forth;
- Higher quality of the printed music sheets, depending on the printer of the final user;
- Possibility of manipulating music notation for transposing, adding annotation, rearranging, and so forth; and
- Possibility of performing a direct music execution from symbolic format to produce MIDI or extended MIDI formats.

All of these features make the use of symbolic music more interesting for music distribution, and therefore its watermarking is very important for music protection.

APPROACHES

According to the user requirements, the printed music sheets must be produced at high resolution and quality. In appreciated music sheets, there is no noise, meaning that the information is in black and white, and therefore no space is left to hide information inside noise or in any kind of noise added-image. This means that the hidden code

Figure 1. Stem rotation approach



can be included only under the shape or in the position of music notation symbols. According to such purpose, some common elements of music sheets can be considered: staff lines, stems, note head, bar lines, and so forth. While stepping into such a direction, it is necessary to find a compromise between quality and watermark readability. Quality is very important for musicians and some minor changes could produce readability problems to musicians. They pay attention to the design of musical symbols, and any detectable variation may disturb the musician when playing. In general, the information to be hidden can be included in the changes considering both their presence and absence, for instance, coding 1 and 0 respectively. In some cases, the magnitude of the change can be used to hide more bits, for example in the orientation, the angle can be variable in order to add more bits.

Stem Rotation

The greatest problems of hiding information in the stem rotation (Busch, Rademer, Schmucker, & Wothusen, 2000) cope with the music score degradation and the low capacity in terms of hidden bits. As depicted in Figure 1, an untrained musician can identify that kind of changes in the music score. This method bothers many musicians when the music is read. In addition, the original music page is needed for watermark reading.

Beam Thickness Modification

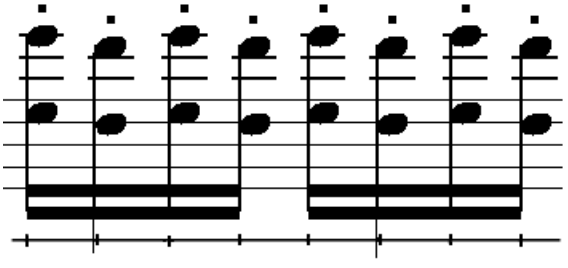
By modifying the orientation or thickness of beam lines, it is possible to hide only a few bits. Another important problem has to deal with the presence of beams which is not guaranteed in the music page. Musicians may easily detect the thickness variation when the beam is placed near a staff line. Furthermore, this method requires the original music page in order to perform the watermark reading.

Noteheads Shifting

The approach chosen by Schmucker, Busch, and Pant (2001) consists in shifting note heads (see Figure 2). The distance among notes has a musical significance. Therefore, in several cases, the approach may disturb the music reading. In Figure 2, the second chord from the left was moved to left, and musicians may detect the missed alignment of the chords. The displacement has been highlighted with the line below the staff and the gray lines. The movement of notes may generate problems when notes are marked with ornaments, accents, expressions, and so forth. In such cases, the movement becomes evident, thus creating a misalignment of notes with the markers. The idea can work things out and hide a significant code length, if there are enough noteheads in the score page.

If considering the main score, the shifted notes are quite easy to be detected by musicians reading them (according to the needs of simultaneity among parts/layers/voices), while it turns out to be quite invisible in single parts. Such a watermark is easy to be detected by musicians in regular groups of notes, provided that the distance among successive notes of the same beam is non-regular/periodic.

Figure 2. Shifting beamed notes approach



Different Fonts for the Same Music Symbol

According to this technique, different fonts for the selected music symbols are used to hide either 1 or 0, depending on the font used. This implies that the font has to be easily recognized during watermark reading. The approach was proposed for text watermarking by Maxemchuk and Low (1997).

Watermarking Images of Music Sheets

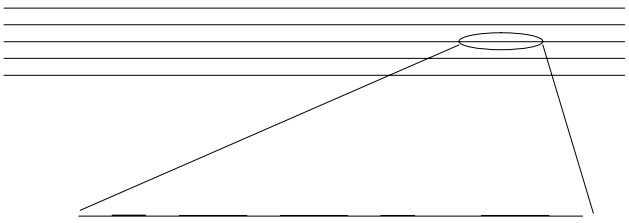
The proposed methods are based on the possibility of storing information by exploiting the relationship of black and white pixels in image segments (i.e., a block) as information carrier (Funk & Schmucker, 2001). The method was elaborated upon Zhao and Koch method (1995) which is based on blocks of distinct size. The ratio of white and black pixels in certain block/area is used to embed a watermark. These areas are treated differently in the process of flipping pixels. The final idea is to embed the watermark only on the black pixels belonging to the staff lines. The fact that the pixel is on a line does not guarantee that it is on the staff line. For this purpose, only horizontal segment having a length greater than a fixed threshold was considered.

Line Thickness Modulation Approach

Figure 3 shows an example of the line modulation. It consists in modifying the lines' thickness in order to insert a binary code made up of several bits. Modulated lines can be easily noted if their presence is known, whereas they are not perceived if their presence is unknown (Monsignori, Nesi, & Spinu, 2001a, 2001b). This approach allows to hide a considerable number of bits in several instances per page, thus making the solution particularly suitable and robust to permit the watermark reading, even out of small parts of the music sheet. This approach has been used in the WEDELMUSIC Editor.

The approach is robust with respect to staff bending, since the watermark is repeated on a large number of staff lines, and it can be read on bended lines. Moreover, a total of 108 bits can be hidden, and a certain number of CRC codes to increase the robustness has been added. This approach can be implemented only starting from the symbolic representation of music notation since the direct manipulation of staff lines on the image may introduce too much noise and produce line deformation.

Figure 3. Staff lines thickness modification



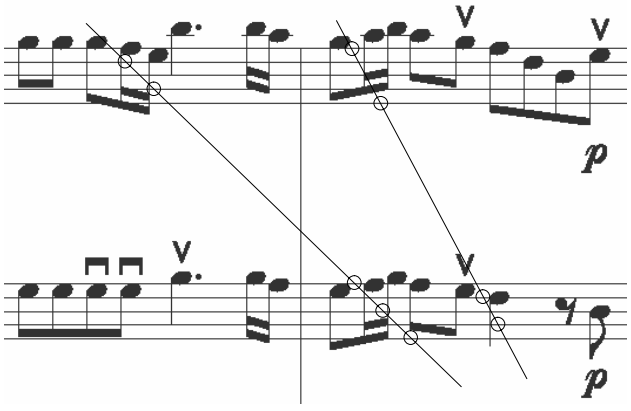
Line Mask Approach

This watermarking approach can be applied to images of music sheet or during the print out of a music score from a symbolic music notation file. The approach consists in marking some points in the music score for virtually hiding a number of lines connecting them (Monsignori et al., 2001a, 2001b). The position and the orientation of the hidden lines are used as the vehicle to hide the watermark code. In particular, the angle between the hidden line and the vertical axis has been used for hiding the information. The idea is not based on writing black lines on the music score (this may only lead up to destroy the music sheet). The points identifying the hidden line may be placed in the intersection among the hidden line and the staff lines, like it occurred with the points in Figure 4, highlighted with circles (in reality, they are interruption on the staff line). In the solution taken, groups of the lines contributing to encoding the same code start from common points. The method allows to hide a large number of bits for each page, and the code can be repeated several time increasing the robustness.

APPROACH VALIDATION

For the validation of these solutions two different phases have to be followed (Monsignori et al., 2003). First, the validation has to be technically performed to assess the robustness against the attacks mentioned at the begin-

Figure 4. Points chosen to be marked in the music score



ning of this article and to verify the effective coding of a large number of bits, repeated several times per page. As a second phase, the validation has to be focused on verifying the real applicability and acceptability of the solution from experts.

The experts' group has to cover the different needs: publishers, engravers, copyists, and many musicians which are the final users. Therefore, they are a very important category for the watermark validation. A specific watermark approach can be unacceptable for the musicians if the music sheet is not readable or annoying for the presence of evident changes. Typically, copyists are the most exigent. The validation has to request the assessment of a sequence of several different music score pages. Some of them are watermarked; others are not. Different levels of photocopy of the same watermarked or not watermarked music sheets have to be included. Different resolutions (dpi of the printer) of the same music sheets have also been used to assess the minimum acceptance level people involved in the validation. All music sheets were printed at the same magnitude, thus the dimension of the staff line was constant. Its value has been chosen according to that most commonly used in printed sheets.

Experts were informed about the main concepts of watermarking and not about these specific changes made in the music score. They have to perform the assessment individually, without being left with the possibility of a comparison with different pages of music and an exchange of opinions among one another.

FUTURE TRENDS AND CONCLUSIONS

As discussed in this article, the technology of music sheet watermarking is quite mature. Several algorithms have been tested and validated on real applications. The effective value of these solutions is similar to the watermark of Audio file. The presence of a specific watermark in the music sheet may be used to demonstrate the ownership of a music piece over the simple presence of textual fingerprints. In addition, the presence of the watermark can discourage people from any possible and intentional copying action of the music sheet for business purposes. The simple copying of the music sheet among friends is not prevented. The future trends of this technology are mainly in its application for monitoring the distribution of music sheets. In fact, the score watermark can be used for hiding code that can be detected during the simple distribution. This permits the content owners to set up specific services to control the data flow and thus to control and detect the passage of their digital items on the network.

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KEY TERMS

Fingerprinting: Used for calling the hidden serial numbers or anything else that should allow to the copyright owner to identify which reseller broke the license agreement. It is used for the multilevel document distribution.

Fragile Watermarking: Techniques that do not guarantee the watermark presence after few document manipulations.

Image Score: An image obtained from a page of music sheet, it can include a main score or a part.

Optical Music Recognition (OMR): Optical recognition of music, transcoding of an image score to a symbolic score format by using a specific algorithm, called OMR.

Robust Copyright Marking: A term used for the techniques that assure a watermark persistence also after the original document was changed in different ways (in the case of the images: cropping, resizing, brightness modification, etc.).

Staff Line: Each single line of the music score staff. The pentagram is made of 5 staff lines.

Steganography: Techniques that allow secret communication, usually by embedding or hiding the secret information (called embedded data) in other, unsuspected data [Joh98]. Steganographic methods are based on the assumption that the existence of the covert communication is unknown and they are mainly used in secret point-to-point communication between trusting parties. As a result, steganographic methods are usually not robust, that is the hidden information cannot be recovered after data manipulation.

Symbolic Score: A representation of the music notation in symbolic, including a description of music symbols and their relationships. This can be done in some formal specific format such as Finale, Sibelius, WEDELMUSIC, HIFF, SMDL, and so forth.

Watermark: The code hidden into a digital or analog object containing an ID (identification) code or other pieces of information. The watermark is used for identifying the fields of embedded data (serial numbers, logos, etc.) that tell us who is the owner of the object or supply an ID in order to identify data connected with the digital object.

Watermarking: Process of inserting a hidden code or message into a digital or analog object. As opposed to steganography, it has the additional notion of robustness against attacks. As the name suggests, the additional data (the watermark) is added in order to protect the digital document from copyright infringements. Even if the existence of the hidden information is known, it has to be hard for an attacker to destroy the embedded watermark without destroying the data itself.

Watermark Reading: Process of extracting the watermarked code into the watermarked object.