Concepts for an Watermarking Technique for Music Scores

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Abstract

Today the quality of copying machines makes it possible for everyone to copy any kind of printed documents without significant loss of quality. Especially copying of printed music is often done. At the same time web-based distribution of music scores in digital representations becomes widespread.

Although copying music scores can't be stopped, it is possible to trace a leak by hiding information in the music score itself. This can be done by watermarking techniques. Two different concepts are presented here: The first regards a music score as an image and uses standard image watermarking techniques. The second is a symbolic approach. Here some music symbols are used by changing their features for hiding information in the music score.

This approach has some advantages in robustness and visibility. By choosing suitable features a blind detection of the watermark is possible.

Keywords: blind detection, music score, watermarking

1 Introduction

Today it is very easy to copy music scores by using a copying machine. The loss of quality is less the better the technology of the copying machine is. In addition to the classical established distribution channels of analog copies, the web-based distribution of music scores in digital format is nowadays accepted and supported by a large number of publishers for example in the project WEDELMUSIC [12]. As a consequence the degradation of each digital copy of a music score is reduced to zero. Because copying music scores can't be stopped, the publishers of music scores want a method to limit the copying.

One possibility is to trace who is responsible for the illegal distribution of copies. Watermarking the music scores is an ideal method for this. A unique copyright information can be embedded in a music score. The use of the ISMN (International Standard Music Number - the national library of Canada offers a good explanation at [10]) is suggested here though other codes can be used as well. This number is comparable to the ISBN and has the advantage of being an independent number. Together with an identification of the customer who bought the music score (using the watermark as a fingerprint) a publisher can easily identify the customer who is responsible for an illegal distribution.

A very important point in embedding a watermark in music scores is not only its (in)-visibility. A musician should under no circumstances be influenced in reading the music. One must even consider the fact of being influenced unconsciously. For example it might be more difficult to concentrate on a music sheet where the symbols were changed invisible.

Another important fact is the ability to read the watermark out of an input source. The most probable way of distributing a music score is the analog form. The music score is copied and distributed. This could happen multiple times. In common it can be regarded that the quality limits the amounts of copies. The tenth recopy could be chosen as the worst acceptable version of a music score for professional use. A watermark should be readable even after these copy procedures.

In the following the image watermarking techniques are mentioned and the difference to our symbolic approach is explained. Then some examples for changing the music score symbols are given. After this possible structures for the watermark reader and writer are shown. A summary finalizes the presented concept.

2 Image Watermarking Techniques

If a music score is given as an image it can be watermarked with standard image watermarking techniques. Music scores are generally given as greyscale images or as binary images. For these different types of images different types of image watermarking techniques must be used.

2.1 Greyscale and Colored Images

In general the properties of the human perception is used for embedding a watermark. For example the human visual system is less sensitive to specific types of noise. This fact is used for embedding a watermark as noise into images.

- *DCT based:* The DCT blocks in the frequency domain are used for embedding the watermark as described in [4] or [2]. For embedding the watermark frequencies in the midband are used. Noise in the lowband perturbates the image very strongly. Watermarks in the highband would be removed by standard JPEG compression.

- *wavelet based:* The image is decomposited according to the wavelet theorem. The resulting wavelet coefficients are used for embedding the watermark which is described for example in [3].

- *fractal based:* The self similarity of image parts is used for embedding a watermark. For example an image part can be modified in that way that the most similar part lies in a specific region. More details can be found in [8].

- *2nd generation:* The so called second generation watermarking schemes change salient image points (e.g. corners) directly by moving them. After these changes a specific statistical measure is satisfied. This field in watermarking is described in [7] or [5].

2.2 Binary Images

In contrast to greyscale images only black or white pixels are possible in binary images. So different schemes must be applied to this image type. One possible solution is dividing the image into regions or blocks. In each region the ratio black to white pixels is changed according to the watermark code which should be embedded.

If the music scores are scanned in a higher resolution, they can easily be converted to binary images without loss of quality. So greyscale images and binary images at high resolution are convertible. Because of this binary images must also be taken into account.

2.3 Binary Images with Specified Locations of Change

An imperceptual watermark is regarded as optimal. But changing pixels in an image independent of its content is perceptual to the human visual system because it reacts strongly to textures and structures. The next step would be limiting the possible locations of change depending on the content of the current block. That means specific types of structure must be recognized and the form in which they can be modified is defined previously. For example the white pixels between note heads and stems can be turned into black pixels.

3 Feature Based Watermarking

Using the previous described methods of image watermarking for embedding a watermark in a music score entails some problems. When a watermark is embedded into a greyscale music score this greyscale image can be binarized without relevant loss of quality. So it will still contain the music symbols but the watermark is lost.

The method of changing pixels from black to white and vice versa can also be applied to greyscale images. But the problem is the low channel capacity. The possibility of adding a watermark is limited. So robustness suffers. This is relevant especially if one considers a copying machine. A copying machine adds speckle noise and changes pixels near edges with higher probability. Some image defects models are presented in [6].

Watermarking binary music scores at defined regions is even more limited. Because only specified locations can be used for embedding the watermark. More possibilities are given if the features of the music symbols are changed not only by adding or removing some pixels. So changing some features of the music symbols will be a promising way for embedding a watermark. Changing the position of musical symbols can be compared with word or line shifting methods described in [1]. But especially in music scores other features can be changed as well.

In the following we list some examples of changing the features of the music symbols. Because of visibility and robustness the modifiable symbols and the way they are modified must be selected carefully.

- *modifications of a single staff*
  - vertical distance between the base lines
- *modifications of systems*
  - vertical distance between staves in a system
  - vertical distance between the systems
- *modifications of the bars (also double bars, repeat bars and final bars)*
  - angle
  - thickness
- *modifications of the musical symbols*
  - *general position*
    * dots
  - *vertical position*
    * ornaments
  - *horizontal position*
    * accidentals
    * meter
    * notes
    * rests
  - *thickness*
    * beams
    * slurs
    * ties
  - *length*
    * extra base lines
    * note stems
    * relative length of half bars
  - *angle*
    * clefs
    * beams
    * notes (stems)
    * chords
    * opening angle of dynamic signs
    * relative angle of 1/4 and 1/8 pause signs
  - *form (stretching)*
    * clefs
    * note head

There is a tradeoff between robustness and capacity for each changed symbol. For example changes between staff lines involves a lot of pixels but only limited amount of information can be embedded.

Some changes are hard to detect by the watermark reader. For example the horizontal position of a note depends on other notes in the system. If a single voice was removed by an attacker this information is lost. So these kind of features cannot be used for a blind detection of the watermark. But other features can be used for a blind detection. The angle of vertical lines (e.g. note stems or bars) and there length (e.g. note stems) can be used for embedding a watermark which can be detected without the need of the original music score.

Some changes of features can be combined (stretching the note head and changing the angle and the length of the stem). But if symbols belong to a group (e.g. triplet) different changes of the same features like the angle can be more visible and sometimes even be impossible like the length of the stem.

Depending on the given music notation only some of the above mentioned symbols can be used. For example music notation for percussions is different to the standard music notation.

4 Watermark Writer

The process of embedding the watermark is dependent on the source format of the input data. Either a symbolic description or an image is given. Accordingly a watermark should be embedded during the printing process or alternatively prior to the distribution in image format, which will be discussed in the following.

Using only parts of certain symbols for embedding the watermark will be easier. Especially if these features are easy to detect and can be changed without interfering their local neighborhood to much. An ideal feature for performing this task are the vertical lines which are contained for example in note stems, bars or clefs. Figure 1 show how a symbol detector can find the vertical lines in the music score, extract them and change them. The first image is the original music score. The second contains the detected features (vertical lines). The third and the fourth one show some possible changes in the angle of the vertical lines.

The example shows how *’011001’* might be encoded in a music score. Different angles are used for embedding the watermark. The watermark positions can be determined by using a pseudo random number generator where the seed was calculated by using a specific key.

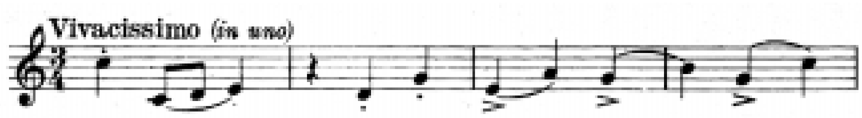
The following table shows how the vertical lines were changed: *’+’* (representing the value 1) is a counterclockwise rotation where *’-’* (representing the value 0) is a clockwise rotation:

no.	1	2	3	4	5	6	7	8	...	16	17
angle	-	+	0	0	+	-	-	0	...	0	+

In figure 2 the results can be compared with the original version. Here still some artifacts are visible which might be removed by image processing operations like morphological operators or Gaussian blur.

The shown example uses only the angle of the vertical lines for embedding the watermark. The advantage of this feature is its independence of other symbols in the same voice or in other voices. A blind detection is possible even if only one voice is given to the watermark reader. Other features like the length of the vertical structure may be used as well. But the length is dependent on the other notes in the group (e.g. triplet). Some features like the vertical distance of notes cannot be used for a blind detection scheme. The vertical distance of the notes is dependent to other voices. Reading the watermark would require the other voices which are in the original music score.

original:



features: vertical lines

changing features: 3 degrees, length remained the same

changing features: 5 degrees, length remained the same

Figure 1: Here is an example of using only the vertical lines for embedding the watermark. The first part contains the original image. The extracted features are shown in the second part. In the third part the features are rotated by an angle of 3 degrees where in the fourth part an angle of 5 degrees is used. Only some vertical lines where changed.

4.1 Embedding the Watermark during the Printing Process

If the source format is in a symbolic format (MIDI, FINALE, ENIGMA format, MusiX-TEX, NIFF, MOODS and others were discussed in the MOODS project [11]) a watermark can hardly be embedded into the source. The reason for this is that there is no noise in the symbolic format. A conversion can be done easily to a unique description which results in the loss of the watermark.

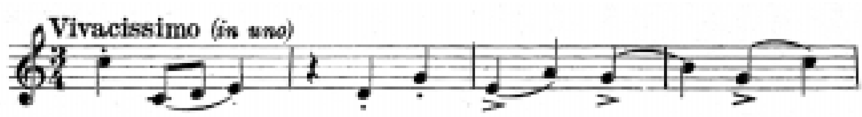
Embedding a watermark during the printing process is shown in figure 3. The embedding can be done as a preprocessing operation for example by using different fonts and then calculating the printer output or as a postprocessing operation where the printer commands are changed.

4.2 Embedding the Watermark into an Image

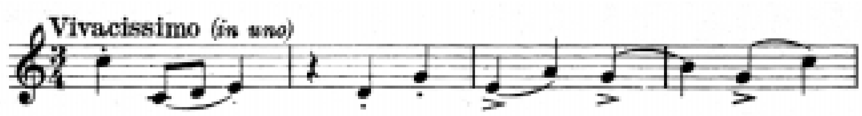
Embedding the watermark into a scanned image score is a completely different task. This task can be split into two units as shown in figure 4:

- symbol detector for finding the symbols: This is the same task which is necessary for the reader. So the functionality of the watermark reader can be used for it, which is discussed in section 5.
- changing the symbols or features: After detecting the features the defined transformations are done on them. Dependencies must be regarded during this process. Inconsistencies must not be created because they influence the musician. For example the hook must be displaced as well if the stem was changed.

changing features: 3 degrees, length remained the same



original:



changing features: 5 degrees, length remained the same

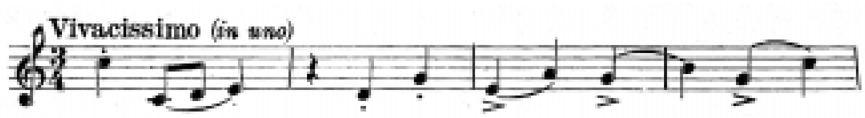


Figure 2: The result of inserting the changed features can be compared with the original image. In the first part the angle of 3 degrees is used and in the third part the angle is 5 degrees. Part 2 shows the original music score.

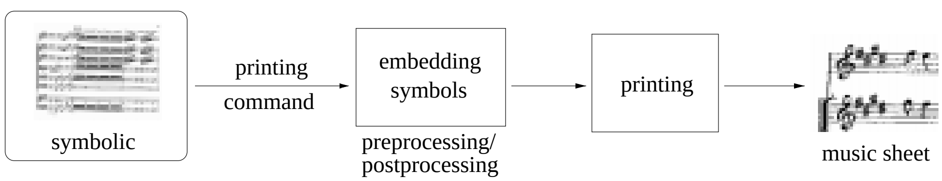


Figure 3: A concept for a printing music score watermark writer.

5 Watermark Reader

A big advantage for the watermark reader is that not all symbols must be recognized. It is even possible using only parts of the symbols (e.g. vertical lines) for embedding the watermark. So recovering the watermark is much more easier than optical music recognition (Further information about OMR can be found at [9].).

The watermark reader must perform several steps for reading a embedded watermark out of an image. The first step is to scan the image so an image file is available.

- *preprocessing:* This step improves the image quality (noise reduction, etc.). Binarising of music scores should be possible without significant loss of quality.
- *base line detection:* The base lines are the guiding symbols of music notation. They can be detected and recovered easily. So they can be used for determining the regions of interest. They can also be used for finding document degradation. But this might be unnecessary because a reference system can be determined. This reference system can give some information for example about the orientation of the staves. So it might be sufficient for detecting the symbols or the features.
- *symbol detection:* The features of the music symbols are used for embedding the watermark. So one possible step is to detect the relevant symbols. But if only some part of a symbol is used finding the relevant structure can be done easier and simpler.

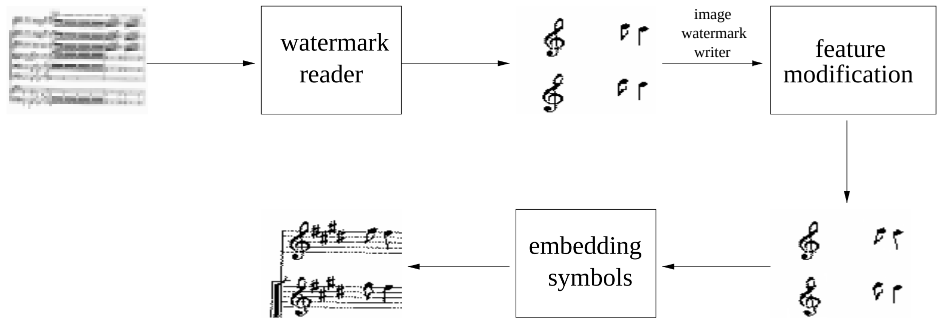


Figure 4: A concept for an image music score watermark writer. The hook must be displaced as well if the stem was changed.

This might be the case for example if vertical lines are used for embedding the watermark. Thus not all symbols which contain a vertical line must be detected. Finding the vertical lines might be sufficient.

- *feature extraction:* After finding the symbols (or the features directly) it is important to determine the changes of the features.

Figure 5 shows the basic concept of a watermark reader. For clarification the computational operations are shown only as partial images. For embedding a watermark the whole image should be used.

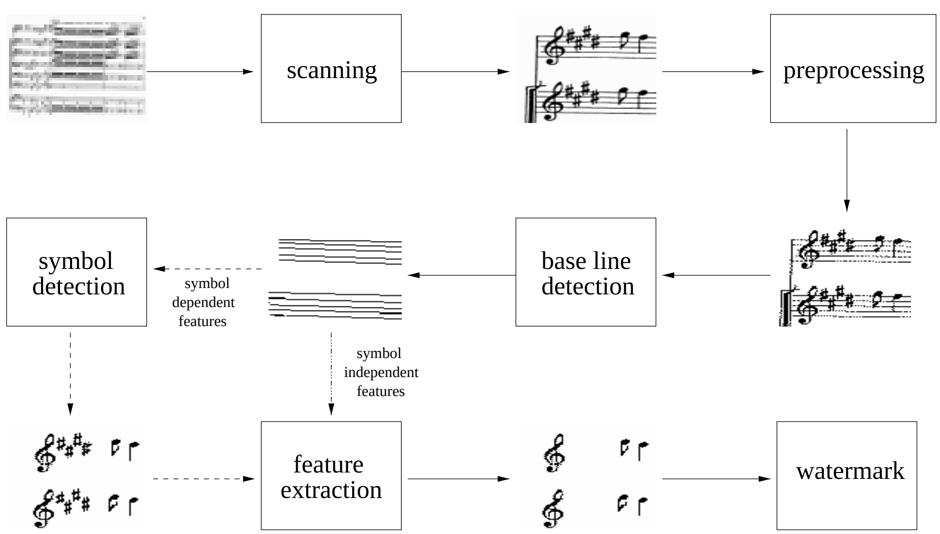


Figure 5: A concept for a music score watermark reader.

6 Attacks

The distortion and noise which is added to the music scores and the transformations applied to it can be categorized in different types.

6.1 Copying of Music Score

The common behavior of people is to copy the music scores they need for playing an instrument at the orchestra or singing in the choir. So reproduction of music scores by using a copying machine can be regarded as the most common way to violate the copyright.

There have be different models used for describing the effects of a copying machine. These models were used especially in OCR (optical character recognition) for examination the detection quality of the software. Some are described in [6].

The most common changes affected by a copying machine are listed below:

- global and local change of brightness and contrast
- asymmetric scaling because of mechanical reasons
- local distortion (e.g. waviness of the baselines) because of fixation problem or because of the spine
- rotation is due to missing alignment
- speckle noise ('salt and pepper') caused by staining of the optical unit
- stripes due to different reasons
- blurring owing to optical effects
- change of pixels near edges

For examining the influence of these changes one must keep in mind that the quality for the musicians must be suitable. While standard image watermarking techniques suffer in robustness using our symbolic approach will still be able to recover the relevant features.

6.2 Scanning of Music Scores

When the music score is scanned the quality of the scanned result depends on the spatial resolution and the color resolution of the scanner. So the edges of the symbols will be affected by the scanning and the quantization process. These effects can be modeled by lowpass filtering and morphological filtering.

For quality examination the same points as mentioned above count here.

6.3 Attacks

Attacks try to remove the watermark consciously. This can mainly be done by scanning the music scores and using some image processing methods.

When the watermark was embedded just by changing some pixels image operations like morphological filters or rotation will probably remove the watermark out of the music scores. On the other hand a symbolical embedded watermark requires much more effort because the symbols have to be check and depending on the result of the check changed individually to remove the watermark. This task is as time consuming as type setting the whole music score.

But one must consider the techniques of OMR (optical music recognition). OMR can be compared to OCR (optical character recognition). But it is still a field which didn't achieve the desired recognition quality yet. If these systems are able to recognize music sheets in acceptable quality it will be very easy to remove any type of watermark just by scanning, converting the image by using OMR and printing the result again. This is due to the fact that watermarking techniques must not influence the musicians. So OMR software is not influenced either.

7 Summary

We presented a new approach in watermarking music scores which changes features of the symbols to embed a watermark. A good result may be expected especially in robustness. Image processing operations like binarisation, smoothing or downsampling can't remove the watermark as long as the quality of the output should be good enough for professional use. For removing the watermark a new typesetting is necessary.

This new approach for watermarking music scores is much more suitable than using image watermarking techniques which can be removed by applying certain image processing operations.

By using suitable features a blind detection scheme can be developed for embedding the watermark into the image. Using only certain features detection and embedding is easier because not all symbols must be identified.

Depending on the possibilities of changing the features in the image we suggest using the same code for printing and image music score watermarking. Thus it is possible to develop one reader that can read the watermark without knowledge of the input data type. For detecting the watermark the reader doesn't need any information about the source format which isn't available. The complete scheme for embedding a watermark into music scores is shown in figure 6.

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http://hpcn.dsi.unifi.it/∼wedelmusic

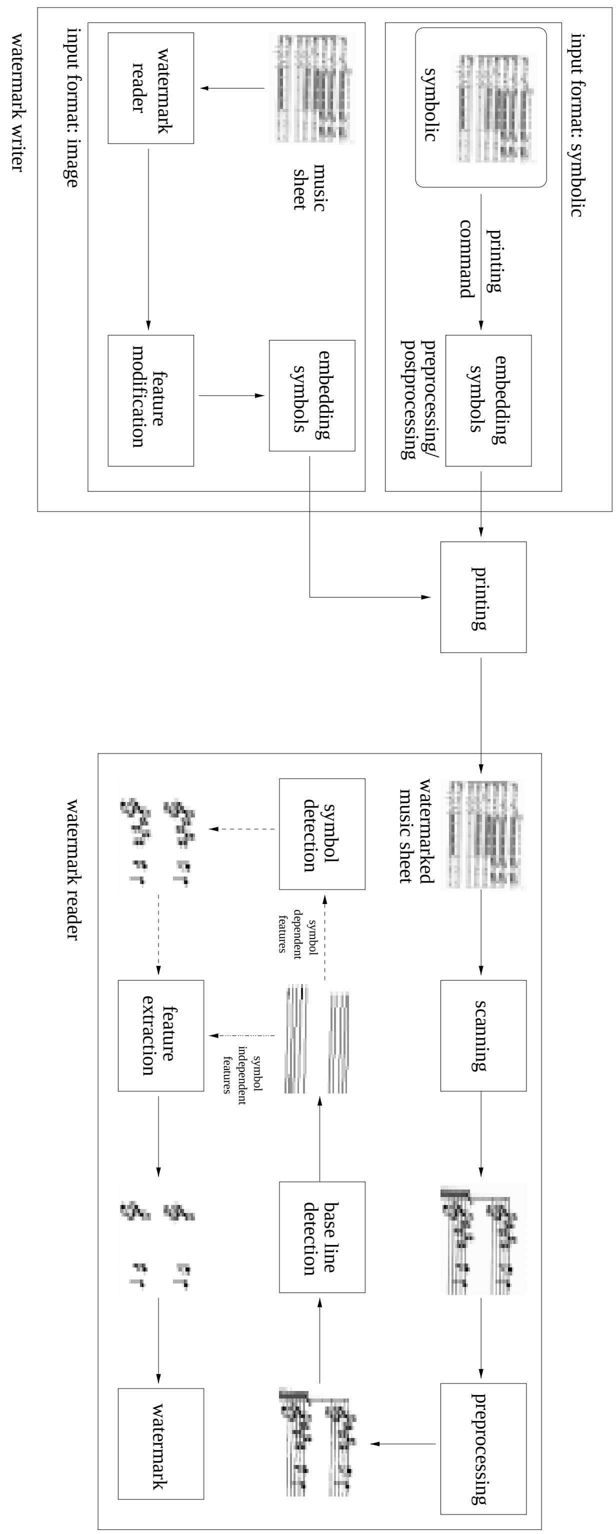

Figure 6: The complete scheme for embedding and reading the watermark. If different writers use the same code for embedding the watermark only one reader is necessary for retrieving the watermark. By choosing suitable features a blind detection of the watermark is possible.