Technology of Music Score Watermarking

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ABSTRACT

Content protection for multimedia data is widely recognised especially for data types that are frequently distributed, sold or shared in digital and via Internet. Particularly music industry dealing with audio files realised the necessity for content protection. Distribution of music sheets will face the same problems. Digital watermarking techniques provide a certain level of protection for music sheets. Classical image-oriented watermarking algorithms for images suffer of several drawbacks when directly applied to image representations of music sheets. Therefore new solutions have been developed which are designed regarding the content of the music sheets. In comparison to other media types, the development of watermarking algorithms for music scores is a rather young technology. The paper reviews the evolution of the early approaches and describes the current state of the art in the field.

INTRODUCTION

In the case of b/w (black and white) images, most of the approaches used for colour images are unusable. For example, for b/w pictorial images, it is unsuitable to work in the frequnecy based transform domain since this implies to generate a unacceptable noise for the musicians. Some other techniques proposed for watermarking can be also considered as possible approaches in music scores watermarking.
The copyright owners (the music publishers, authors and/or distributors) have in their archives high quantity of music scores. In classical music, the original music is normally stored on paper since it was produced several years ago. Presently only new light and popular music pieces are in symbolic notation formats. Light and popular music have a limited live span in terms of time duration in comparison with classical music pieces. Publishers keep their distance from transforming their classical music pieces in digital format for e-commerce purposes since whenever distributing in this way their copyright ownership is not protected. Therefore, classical music risks remaining in the archives of publishers and libraries since its distribution is too dangerous for the future business of the copyright owners. The life of the copyrights for that kind of music is close to 60-80 years. Current copyright infringement is only via photocopy process. The Internet distribution risks to be an efficient vehicle for losing the control on this material. The situation is different for light and popular music where the market life is shorter.
E-commerce for music distribution is not acceptable for publishers without the support of adequate protection mechanisms. Publishers prefer to protect their music and at the same time to allow the users exploiting content functionalities according to the permissions and prices established by the publishers. To cope with these problems, mechanisms for protecting musical objects include:

- encryption techniques to support the transferring 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;

If a good and complete protection model will be developed and profitably validated, many publishers could decide to publish their classical music pieces on Internet and this will have surely positive effects on the music sheet market:

- The music should be bought in real-time;
- The distribution will not be limited to geographical areas;
- A further evolution of music software (editors, delivering systems, commercial tools, etc.) might be expected;
- Moreover, very ancient music sheets are interesting for artistic and historical aspects, especially if hand-written.

The field of music application quickly evolves, giving to the publishers, or in general to the music copyright owner, the possibility to use the new technologies in order to improve their activity.

The chapter continues with a brief description of several possible approaches for watermarking music sheets and with a complete description of a technique that was implemented as the best result of our research. Please note that the work available on watermarking music sheets is really limited at two research groups that produced the results for the Research and Development Project called WEDELMUSIC.

BACKGROUND

The music scores availability changed during the years. At the beginning the music was described with a low number of symbols by using the state-of-the-art technologies. The paper was used as a support for the music scores until few years ago. Today the symbolic representation of music has conquered more application fields and numerous musicians started to use new technologies for writing and manipulating music.

Music on sheets not always satisfies the music consumers that frequently need to make changes (adding annotations) on the music that they buy. The music scores are really used day by day. This is quite different with respect to a book that is typically read once or twice. If a user makes copies their quality quickly is not good. Digitized music sheets could give a lot of advantages in that sense. A musician could print several copies of the music that he bought, and changes could be saved into a safe digital format.

A first possible, low cost solution can be to acquire the music sheet with a scanner. An image music score is only a photographic copy; it has a number of considerable disadvantages. The most important is that the technology capabilities in manipulating digital contents are not used. The music scores in image format are not editable. This important issue is the reasons that motivate young musicians to buy music editors. They manipulate what we call *Symbolic Music Notation.* The symbolic notation it is obviously stored in digital in files of the computer and can be used for producing the music sheet as well as for producing an annotated version of it, if the changes are made with the same music editor used for creating the music sheet.

A digital symbolic music score at any given moment can be edited and copied an infinite number of times, with a far superior quality of print. Also the symbolic music editors allow the synchronization between various type of digital music (symbolic, images, MIDI audio, MP3 audio, etc.), (Bellini et al., 2001), (Bellini et al. 2003).

In order to understand each musical symbol an analysis can be performed on the musical content and not only on the music external characteristics it is needed to consider the capability of music editor. For instance by using a music editor it is possible to search specific sequence of notes in numerous scores, to make transposition for different instruments, to make a piano reduction, to change the lyric, to annotate and make deeper changes in the structure of the music.

Anyway, today the music scores are available on paper at 90 percent. The situation change rapidly since a big number of publishers started to digitize in a massive manner their music scores archives.

Watermarking Music Sheets - Approaches Description

In this section, before presenting the possible algorithms and techniques for watermarking music sheets some general requirements are exposed and discussed. Also an analysis of the embedded data is shown. Most of the described approaches were analyzed and tested during the early phases of our research. Others were collected from the literature (Busch at al., 2000), (Funk at al., 2001), (Schmucker at al., 2001), (Zhao at al., 1995). A possible application in music score watermarking of the approach shown in (Maxemchuk and Low, 1997) is also introduced.

Requirements

The requirement have been collected by means of a set of interviews to the experts of WEDELMUSIC project user group. The user group is mainly inclusive of musicians, copyists and music publishers. The identified requirements can be divided in three categories:

Content requirements:

- The embedded data has to contain the publisher identification, the music piece identification and the music distributor identification. In alternative, the embedded data may contain a simple identification code, ID, that allows getting the former information by simply consulting a WEB service.

Visual requirements:

- The watermark inserted in the printed music sheet has to be invisible for musicians or at least it must not disturb during the music playing.
- The watermark has to be present inside the music printed by the final user in any format if the music is available in symbolic format. Thus the watermark reading has not to depend on the availability of the music sheet's reference image.

Resistance requirements:

- The cost to remove watermark must be extremely expensive if compared to regular buying.
- The watermark must resist during sheet manipulation until the music printed becomes unreadable. 5 levels of photocopy are sufficient to make music unreadable or of low quality.
- The watermark should also be readable by processing a smaller piece of music sheet (greater than ¾ of the whole music sheet page) although a copy of a small part of the score does not represent a high commercial value.

- Processes of digital filtering, zooming, rotations, cropping, noise addition, flipping, etc., must be considered less probable manipulations since they are strongly time consuming (their cost can be comparably similar to the price of the music sheet, for a music score can include 30 pages) and too technical for the majority of end-users whose background is that of a musician.

Other typical watermark parameters have been taken into account in order to analyze the technique capability.

- The amount of embedded information has a direct influence on watermark robustness. More information is embedded, lower the robustness becomes. This is due to the following reason. The hidden code is repeated several times in the same page; therefore when the code is big, the number of times it can be repeated is lower, thus decreasing 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.

Data capacity

A very important question is the information that should be stored during the watermarking process. This is limited by the number of music notation symbols that can be changed and how these symbols can be changed without degrading the readability. This is generally called the capacity of the information channel used for watermarking.

Watermarked code

Another important question is what kind of information the watermark should contain.
It is necessary to embed the copyright information for the identification of the right owner and also to keep a trace about the origin of the scores in order to find the path of distribution. According to the analysis performed in our research the whole watermark code should be divided in two parts:

1. copyright watermark. **<publisherIDcode><component type><component number>**
   Totally there are 12 digits alphanumeric number = 72 bits
2. user watermark **<LDID>**. The content of this part will be the distributor ID, which is a 6 digit alphanumeric number = 36 bits

The total number of bits to be embedded into the image can be 108. Some control sequences (hash, CRC or start/end sequences) should be needed. This information can be changed during the algorithm developing and the number of bits should be variable because of synchronization problems.

Implementation Environment

The great majority of the music scores are still on paper in the publisher's archives. A first way to transform them in digital documents can be to transform them in images using a scanner. Another possible way can be to transform them in symbolic music by using a music editor. Obviously the second way is very expensive since the music have to be totally retyped. The comparison of very efficient OMR (Optical Music Recognition) software similar to the OCR (Optical Character Recognition) seems to be quite improbable in the near future.

After the digitalization of the music images or symbolic music are obtained. These digital documents are different in quite all their characteristics. For example, in case of text acquisition the scanned image is just a photo of the original; the retyped text file instead, give to the user the possibility to use all the text editor capabilities for manipulate it. In the case of the images no successive music manipulation is possible and only few changes can be performed to the image. An advantage is that the images can be easily viewed in any operating system and with an infinite number of applications.

The symbolic music allows to the user to modify the music, justify it, change the page settings, etc. It can be considered as a kind of source code for the music. The disadvantage is that all these operations can be performed only if the music editor is available, and professional music sheets are typically produced by expensive and professional music editors. On the other hand, music editor builders provide simple viewers that in most cases do not guarantee the digital right management, DRM.

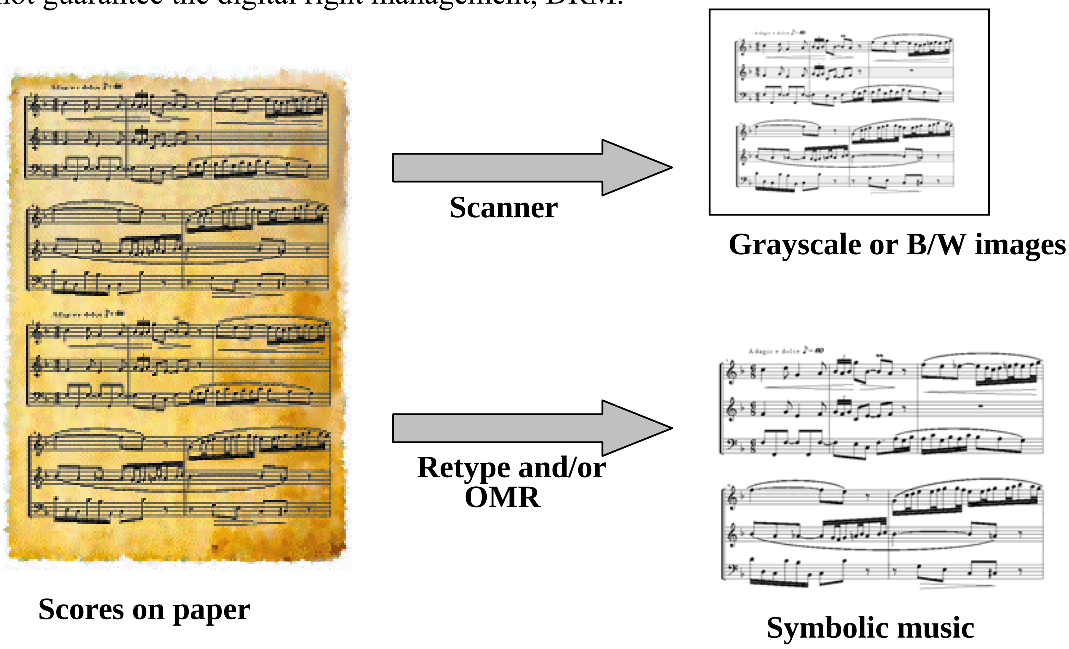

Fig. 1 Music score digitalisation

It is well known that the music sheets are distributed in paper format between the musicians. Therefore, it seems that the digitizing process is useless. In practice, music sheet distribution via Internet, from publishers to consumers, can only be realized only by using digital formats. The distribution among consumers such as now with the photocopy could be even via digital music sheets, as occurred with audio files on Napster. Please note that on P2P (peer to peer) application there is also a quite significant distribution of music scores.

Also by using the digital formats the music will be converted again on paper (today the musicians play the music only from paper sheet). This mean that some printing capabilities have to be given to each software tool that manipulate music scores.
After printing, the music score comes back to his originally format after changes performed in digital format.

Watermarking images or watermarking symbolic music lead to obtain the same result. The watermarked music (symbolic or image) should remain in digital format in some not changeable file formats (like PDF) or in difficult changeable formats (PostScript).

In the next section, the described approaches are intended for the above mentioned two digital formats of the music scores. The implementation of the related algorithm for music watermarking is completely different in the two cases.

System Architecture for Watermarking while Printing Symbolic Music

The system architecture provides (as any other watermarking system architecture) a watermark writer process and a watermark reader process (see Fig. 2).

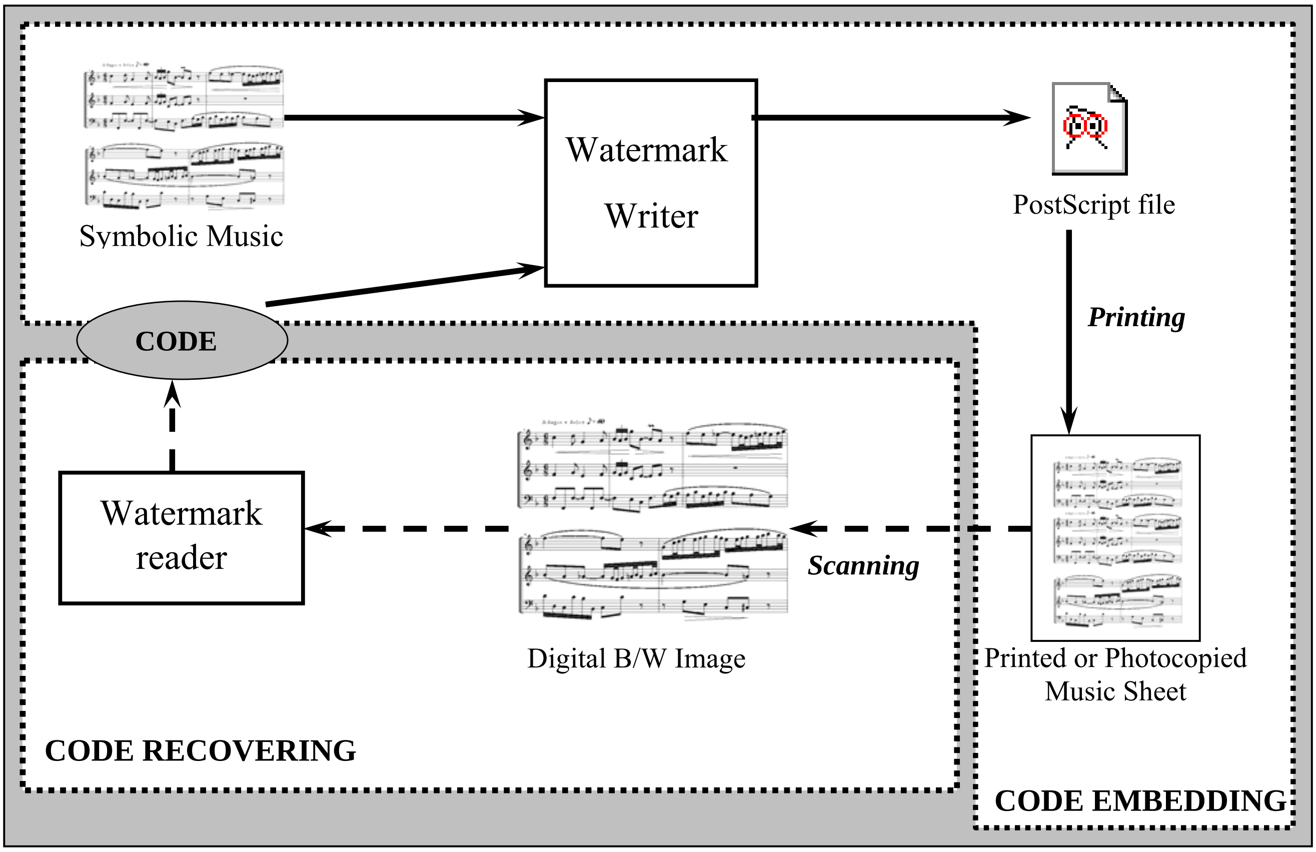

Fig. 2 - System architecture for music sheet watermarking while printing

The code is inserted in the music score when the print command is activated in a music editor (such as WEDELMUSIC). The process may generate a PostScript file or may send the information directly to the printer. In order to read the code hidden in the watermarked music sheet, it has to be scanned and the resulted image has to be elaborated with the watermark reader, which reconstruct the embedded code.

Approaches Overview

In this section, a short overview of several experiments on watermarking music sheets is reported. According to the requirements of publishers, the printed music sheets must be produced at high resolution and quality. In appreciated music sheets, there is no noise, meaning that the information are in black and white and therefore no space is left to hide information inside noise or in any kind of noise added-image. It means that the hidden code can be included only in the shape or in the position of music notation symbols. According to

such a purpose some common elements of music sheets can be considered: staff lines, stems, note head, bar lines, etc.
While stepping into such a direction, it is necessary to find a compromise between quality and watermark readability. It is a hard work since 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 variation may be detectable and may disturb the musician during the music playing.
The techniques herewith considered can be split in two categories:

- Transformation of music elements.
- Adoption of different fonts for the same symbol.

In the approaches based on the transformation of music symbols such as staff lines, bar lines, beams, stem or slurs (ties) are manipulated. The most significant examples are:

- modifying the orientation of note stems,
- modifying the position of the notes on the staff,
- modifying the orientation of beam lines,
- adding white dots in the middle of other bigger music notation symbols,
- modulating staff lines by giving them different thickness, and considering thinner segments 0 and deeper as 1,
- modulating staff lines to give them a sort of sinusoidal behavior, etc.

In general, the information to be hidden can be included in the changes considering both their presence and absence, as 1 and 0 respectively. In some cases, the magnitude of the change can be used for hiding more bits, for example in the orientation the angle can be variable in order to add more bits.

Stem Rotation

The major problems of hiding information in the stem rotation (Busch at al., 2000) are the music score degradation and the low capacity in terms of hidden bits. As depicted in Fig. 3, a non-expert musician is capable to identify that kind of changes into the music score. This method bothers the musicians when the music is read. In addition, it needs the original music page for watermark reading.

Fig. 3 - stem rotation approach

Beam Thickness Modification

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

Noteheads Shifting

The approach chosen by Schmucker at al. (2001) consists in shifting note heads (see Fig.4). The distance between the notes has a musical significance. Therefore, in several cases the approach may disturb the music reading. In the figure, the second chords from the left was moved to left and the 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 the notes are marked with ornaments, accents, expressions, etc., in those cases, the movement becomes more evident creating a misalignment with the markers. The idea is good but unfortunately is feasible only for specific music score: with a large amount of notes and if the nearly staffs does not contain beams.

The idea is suitable to hide a significant code length if a sufficient number of noteheads are present into the score page. Typically, the number of notes in a score image is quite low, it ranges from 10 to 50 for each music staff. A score page may have from 7 to 15 music staffs. This solution requires the original music page for watermark reading since the difference with original position of the notes has to be taken.
If considering the main score, the shifted notes are quite easy to be detected by the 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. If the shift is too evident, it may become a problem the musicians, since it might give the impression that some changes in the note duration were imposed.

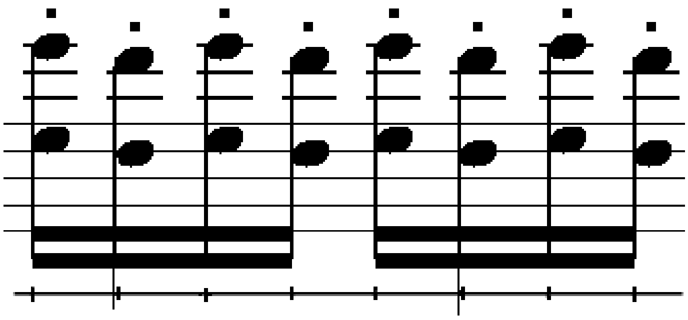

Fig. 4 - shifting beamed notes approach

Adding white Dots

This approach consists in adding small white dots into larger music notation symbols (see Fig. 5). The results can be quite easily detected by musicians and are not annoying while playing music. This is not a robust approach, since a mere photocopy may destroy the dots when they are smaller enough to be acceptable by musicians. This solution encounters the same failure and problems as previously explained for the low number of noteheads which are present in a core page. The number of bits, which can be hidden in the music page, depends on the number of notes, which are on the same page.

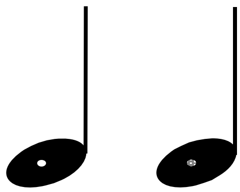

Fig. 5 - Inserting a white dot into note head

The approaches based on changing single music notation symbols are unsuitable since they neither allow hiding a high number of bits nor permit to replicate the code several times in the same score page to increase code robustness.

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 in the phase of watermark reading. The approach was proposed for text watermarking by Maxemchuk at al. (1997).

Fig. 6 - different font for the same note

Fig. 6 shows an example of possible font modification. The original character (on left) was changed by modifying flag thickness (on centre) or length of the hook (on right). An undefined number of small changes can be performed on musical symbols in order to add the watermark. In some cases, the same character may present 4 different forms in order to hide 2 bits of the watermark code. The problem in using this technique is related to the channel capacity (since it is also a method based on symbol modification). The difference with respect to text watermark is that in music language the number of "characters" on a page is smaller. Therefore, it may became difficult to hide the whole code in a single music score page.

Image Watermarking Approach for Music Sheets

Binary images consists either of ’1’s or ’0’s (white or black pixels). The frequency domain cannot be used for embedding a watermark. The only possibility to store information is to exploit the relationship of black and white pixels in a certain environment (i.e., a block) as information carrier (Funk and Schmucker, 2001). Therefore the method of Zhao and Koch (1995) is based on blocks of distinct size. The ratio of ’1’s and ’0’s in a certain block b is used to embed a watermark.
The rate (percentage) $P_1(b)$ of black pixels in a selected block b is defined as:

$$P_1(b) = N_1(b) / \#b$$

where N_1 (b) is the number of ’1’s in the block b and #b its size.
The sum of percentages of black and white pixels in block is 100%. Therefore the rate (percentage) $P_0(b)$ of white pixels is:

$$P_0(b) = N_0(b)/ \#b = 100\text{-}P_1(b)$$

On the one hand, a '0' is embedded in a block b if $P_1(b)$ is greater than a given threshold t_{upper}. On the other hand, a '1' is embedded if $P_1(b)$ is less than another given threshold t_{lower}. Embedding is done by flipping some of the pixels in a block until the rate $P_1(b)$ is in a certain embedding range which is given by λ which should be considered as a robustness degree. So the resulting rates of the watermarked blocks are:

- embedding a '1': $P_1(b) <= t_{lower}$ *and* $P_1(b) >= t_{lower} - \lambda$
- embedding a '0': $P_1(b) >= t_{upper}$ *and* $P_1(b) <= t_{upper} + \lambda$

Two different areas in binary images are distinguished by Zhao and Koch according to the distribution of black or white pixels in it. These areas are treated different in the process of flipping pixels.

- In dithered blocks where black and white pixels are well interlaced the modifications are well distributed in the whole blocks.
- In sharply contrasted blocks with clear boundaries between black and white pixels the process of flipping pixels is applied at the boundary of black and white pixels.

In Funk and Schmucker (2001) a technique based on Koch and Zhao method has been presented. In order to improve robustness and invisibility some changes were performed on the number of blocks, thresholds and block size. A more important changes has been to separate the image black pixels in two sets in order to differentiate between pixels belonging on musical symbols and pixels belonging to line segments (horizontal or vertical).
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.

MAIN THRUST OF THE CHAPTER

The techniques previously introduced have several problems in satisfying the user requirements. Some of them are not capable of hiding the needed code length; others are based on the image manipulation (see also (Deseilligny at al., 1998)) so cannot be used for a real time print from the symbolic music editors. A good music score watermarking system should be useful also when the user can manipulate the music in a symbolic format (change number of staffs per page, eliminate some measures or add comments and then printing the modified score in the printer at home). The watermarker has to be quick enough in order to embed the code after the user push the print command and before the printer go to perform the action. Also the research on text watermarking produces some valuable results (Brassil at al., 1995), (Brassil at al., 1999), (Low at al., 1995), (Maxemchuk at al., 1994). Unfortunatly most of these techniques are not useful for music sheet wateramarking except for those based on using different fonts (Maxemchuk at al., 1997).

Solution and Recommendations

Different possible approaches already presented in (Monsignori at al., 2001a), (Monsignori at al., 2001b), (Monsignori at al., 2001c) are better analyzed in the next sections since they seems to offer more guarantees in satisfying the user requirements.

Line Thickness Modulation Approach

Fig.7 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. This was confirmed during our validation phase by a group of experts.
This approach enables to hide a considerable number of bits in several instances per page. This makes the solution particularly suitable and robust to permit the watermark reading even out of small parts of the music sheet.

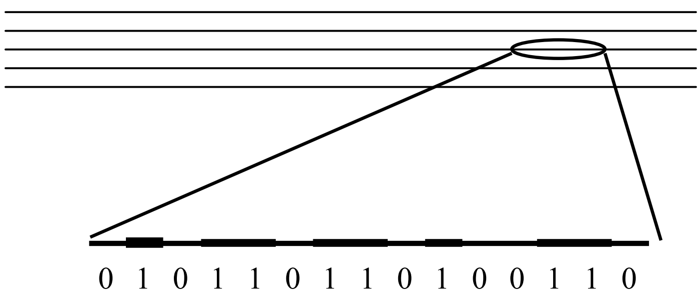

Fig.7: staff lines thickness modification

Watermark Embedding Process

As described before the process to insert the code into a digital document is called watermark embedding. For this approach, if the symbolic music notation is available, the embedding process can be performed during the printing of music score from WEDELMUSIC editor. The data needed for the code creation are stored in an encrypted file stored on the reseller server. In Fig. 8, this file is called “header”. During the music editing/visualizing no changes are made on the display. When the “print” command is activated the editor printing process includes the watermark, the hidden code that allows to identify the music piece univocally as produced by the right owner.

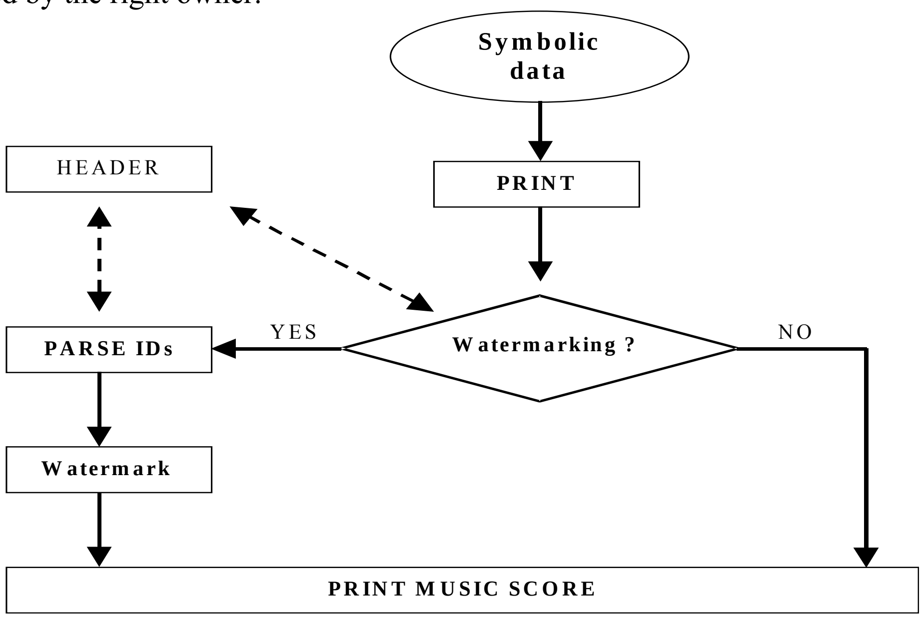

Fig. 8 - Embedding process phases

In order to ensure optimal results for the reading process without degrading the music sheet, several decisions have been taken for implementing the approach:

- The length of the single bit in terms of dot per inch (dpi) in the printed music sheet is calculated before the generation of the printed page. It mainly depends by the length of the staff.
- For the thickness of the line in case of zeros and ones, the 2/300 dpi and 3/300 dpi values were chosen after analysis of quality degradation and watermark reading results.
- Before a preliminary analysis it was decided to place the starting point of the code after the (first) clef founded in the staff (see Fig. 9). This decision was taken because the clefs cover a large part of the staff lines and thus that area is not usable to hide the data. The systematic misdetection of beginning of the code covered by the clef could be recovered by the processing of the replicated code on all the staff lines at the expenses of the robustness.
- During the image acquisition for watermark reading some deformations could be found. For a better estimation of the code length, between the two codes inserted on the same line a number of zero bits coded were added (see Fig. 9) to get the perfect beginning of the code. In addition, in order to correct some wrong detected bits a CRC, cross check control bits, were added.

As previously described the watermarked code can be built as follow:
- copyright watermark : comprised of 12 alphanumeric digits = 72 bits;
- user watermark comprised of 6 alphanumeric digit = 36 bits.

For a total of 108 bit + 1 start byte + 5 bytes of CRC = 160 bits. In order to improve the approach robustness some CRC blocks were added. On every set of 3 bytes a CRC was added, finally a CRC to verify the correctness of the partial CRCs gas been also added. In this way errors in receiving wrong bits can be easily corrected.

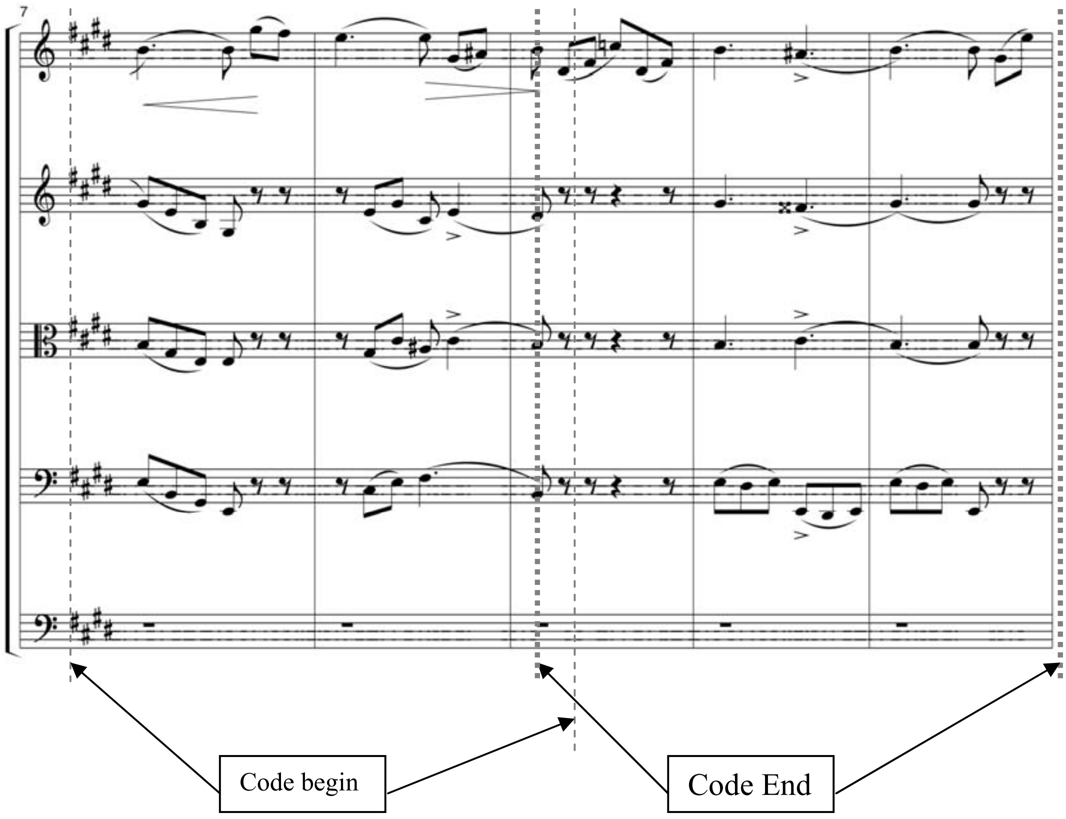

Fig. 9 Code positioning in a system

Watermark Reader

In this section, the algorithm used for reading the watermark code from a scanned music sheet is described. According to the solution chosen, in order to read the watermark it is not needed to have the original music sheet with or without watermark since the watermark is directly read from the line modulation. The bitmap image of the music sheet on which the user has to verify the presence of watermark has to be acquired by using a scanner. The scanned music sheet is elaborated in order to enhance its contrast. After this first phase a set of steps have to be performed in order to read the watermark code:

(1) Delimitation of staffs. This task is performed using the classical segmentation algorithms based on histogram profiles of OMR such as in (Marinai and Nesi, 1999)..
(2) Delimitation of single staff lines. Also in this case, detection is performed using histograms as above.
(3) Tuning phase to: (i) estimate the thickness values assigned to 1 and 0 values of the thickness line modulation, (ii) to verify the presence of the watermark. (see in the following);
(4) recognition of the watermarked lines (see in the following);
(5) extraction/reading of the watermark code (see in the following);
(6) verification by means of control/correction bits of the correctness of the read code and eventual corrections. It consists in processing the binary sequence obtained in order to verify its correctness. To this end, together with the effective watermark code, some control/correction bits have been inserted in order to identify, and in some cases correct, the presence of wrong bits.

In the following, only the most important steps are detailing described.

(3) Tuning phase

The phase of tuning is performed in order to estimate the thickness values of the line modulation representing the 1 or 0 of the watermark code. These values are influenced by the operations that have been performed on the music sheet. For instance, a music sheet printed 300 dpi and acquired at 600 dpi may have the line thickness between 4 and 6 pixels. When the image is photocopied the thickness typically changes of a unpredictable amount due to the scaling effect of photocopy. The precision of estimation of line thickness corresponding to 1 and 0 is fundamental for the correct reading of the watermark. Therefore, the first step is to verify if the score music under elaboration is watermarked or not, and at the same time to estimate the thickness values associated with 1 and 0 bit values. To this end, the following estimations are performed.

The following function h represents the thickness of the staff lines:

$$h_k[i][j]$$

where:

- **k** is the staff number in the page (from 1 to number of staves in the page, MAXSTAVES)
- **i** is the line number in the staff (from 1 to 5)
- **j** is the horizontal position in pixels (the maximum value, jMAX, depends on the acquired resolution. For a 600 dpi scanner resolution jMAX is close to 4500)

If we establish a running window around the staff line that run from the left to right of the page, the value of the above function is comprised between 0 and the height of the running window, *H*max. For any value of $x \in (0, H\max)$ the following counting function is defined as:

$$V_i^k(x) = \sum_{j=0}^{jMAX} \gamma(h_k[i][j], x)$$

where

$$\gamma(h_k[i][j], x) = \begin{cases} 1 & if\,(x = h) \\ 0 & otherwise \end{cases}$$

$V_i^k(x)$ is calculated for each staff line of the page (or part) under analysis. Then a mean value *M(x)* is calculated as:

$$M(x) = \frac{\sum_{k=0}^{MAXSTAVES} \sum_{i=1}^{5} V_i^k(x)}{5 * MAXSTAVES}$$

In addition, the mean value of the displacement with respect to the mean value of *M(x)* is obtained as:

$$F(x) = \sum_{k=0}^{MAXSTAVES} \sum_{i=1}^{5} \hat{V}_i^k(x)$$

where

$$\hat{V}_i^k(x) = \left| V_i^k(x) - M(x) \right|$$

Plotting *F(x)* function a cumulative histogram of the line thickness is produced as reported in Fig. 10. In this graph two peaks are presents. The position of the peaks represents the thickness associated with 0 and 1, respectively. The example shows a case in which the line thickness associated with 0 has measured to be 7 pixels while the line thickness associated to 1 was of 9 pixels.

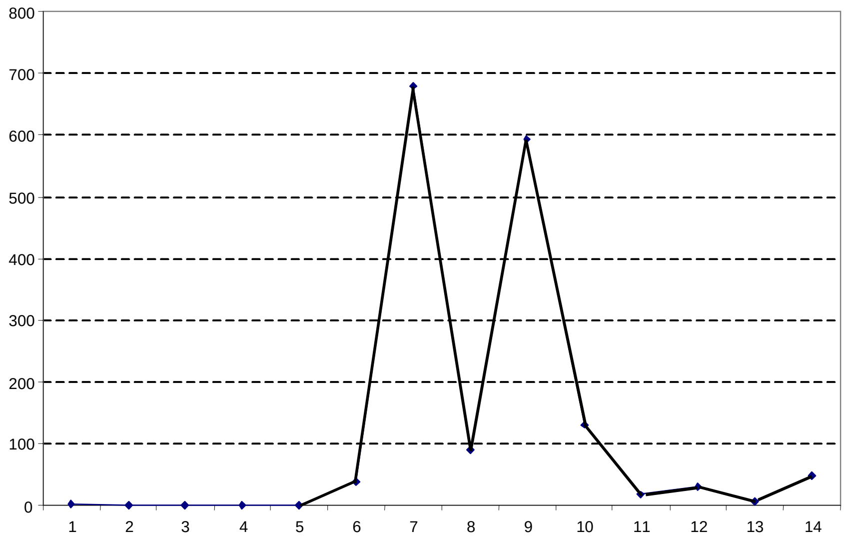

Fig. 10 Cumulative histogram of the line thickness, F(x)

Please note that non-watermarked lines contribute to the lower peak, while in watermarked lines a comparable number of 1 and 0 can be foreseen. When only one peak is present the music score under analysis does not present the watermark or it is not anymore readable.

(4) identification of the watermarked lines;
A statistics analysis about the line thickness performed on each staff line allows distinguishing the lines that have been marked from those that are non-marked. For each staff line, the displacement, $\tilde{V}$ (x), with respect to the mean value *m(x)* is estimated:

$$\tilde{V}_i^k(x) = V_i^k(x) - m_k(x)$$

where

$$m_k(x) = \frac{\sum_{i=1}^{5} V_i^k(x)}{5}$$

Plotting $\tilde{V}$ (x) different results are obtained for marked and not marked lines (see Fig.5.6).

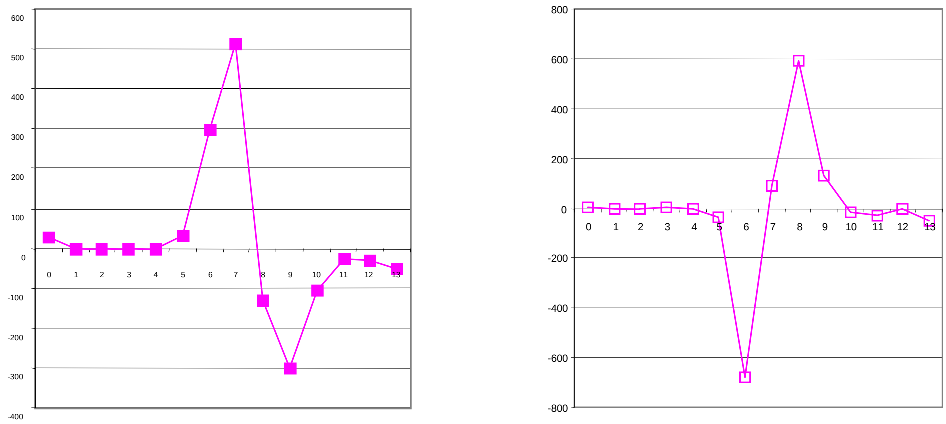

Fig. 11 The $\tilde{V}$ (x) function for the staff after scanning the music sheet

The graph on the left side represents the behavior in the case of absence of watermark, while that on the right denotes the presence of the watermark. The first peak is positive in the first figure and negative in the second. This method is used for distinguishing watermarked lines.
Obviously, the identification of the marked lines is influenced by the presence of musical symbols on the lines (noteheads, beams etc.). On the other hand, the estimations are performed on about 4500 points. This makes the estimation confident. For example, the graphs reported in Fig. 12 show the same functions after the third photocopy.

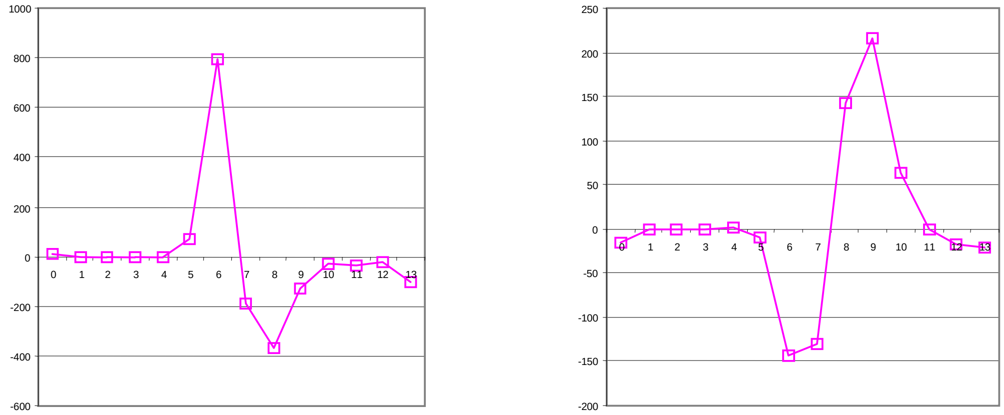

Fig. 12 - Plotting results for watermarked (right) and not watermarked lines (left)

(5) extraction of the watermark code;

Once the watermarked lines are identified, it is possible to proceed at the watermark reading. The watermark code is included twice for each line. A code is comprised of 160 bits and thus 320 bits for each line. Since a staff is about 4500 points we used about 14 points for each bit. In order to make it less visible only two staff lines on the 5 of the pentagram are marked. Thus 4 watermark codes are included for each staff. Typically in an A4 page about 10 staffs are present, then each page presents 40 copies of the same watermarked code. This confers a high robustness at the approach.

On the acquired images on which the watermark has to be read a horizontal distortion of the image and rotations can be present. These can be due to the acquisition by means of scanners or due to the photocopy. The rotation can be easily removed by using histogram-based approaches. The horizontal distortion leads to transform in an unpredictable manner the length of the watermarked code.

In order to solve this problem, the beginning and the end of the watermark code are marked with a sequence of bits (11001100), 1 byte. In this way, the position of the watermark code is identified. This allows to

1. align the watermark codes read from all the available staff lines, up to 40 in a page, to obtain a cumulative function $\widetilde{V}$ (x) for all the watermarked codes.
2. superimpose a grid to read each single bit with the sequence of the values of cumulative function $\widetilde{V}$ (x)

In some cases, musical symbols cover a part of the staff line and thus of the watermark code becomes unreadable in that point. On the other hand, the possibility to align more watermarked codes (of the same staff or of other staffs) allows overcoming this problem.

The code recovering process uses the principle of the embedding process. For each staff, it is determined the modulation step p_j, that is the length of the line segment on which the single bit is encoded.. The value of p_j is calculated by dividing the staff line length with 360 (number of bits encoded). This value is a good approximation of the real value of the segment (in practice each value has to be verified and re-estimated because of the distortion inserted by photocopying process). It is assumed that the staff was not cut (in that case the music is useless).

After to have identified the starting point s_j, the end point e_j and the modulation step p_j the single bit intervals $\left(b_{k,}^{j} b_{k+1}^{j}\right)$ are evaluated.

It is known that $b_0^j = s_j$ and $b_k^j = s_j + kp_j$ where $k = 1,2, \ldots N_{bit} - 1$

In some cases, as a music sheet manipulation effect, or because of symbols covering the staff line some thickness values can be useless for the bit value calculation. These values have to be eliminated. If H_0 and H_1 are the thickness associated to 0 and 1 respectively a parameter ε is introduced as maximal variation. The thickness values out from the interval (H_0- ε, H_1+ ε) and the values equals to (H_0+H_1)/2 are replaced with the thickness predominant value (H_0 or H_1). By making this, final estimation will gain in precision.

The mean value for the thickness is calculated as:

$$\overline{H}_k = \frac{\sum_{j=0}^{N_{seq}} \overline{H}_{b_k^j}}{N_{seq}}$$

The binary value of bit k is given by:

$$B_k = \begin{cases} 0 \text{ if } \overline{H}_k \leq \dfrac{H_0 + H_1}{2} \\ 1 \qquad\quad \text{otherwise} \end{cases}$$

In the previous formula the value (H_0+H_1)/2 was assigned to the low bit value. The decision was taken because for several reasons:

- for each thickness value a bit value has to be assigned;
- the probability to have the mean value is very low;
- the zero bit is less subject to distortion (H_1 can be found also in case of symbol overlap or in case of distortion, H_0 can be considered as indicated the zero embedded value)

Figures 13 and 14 describe the watermark reading process.

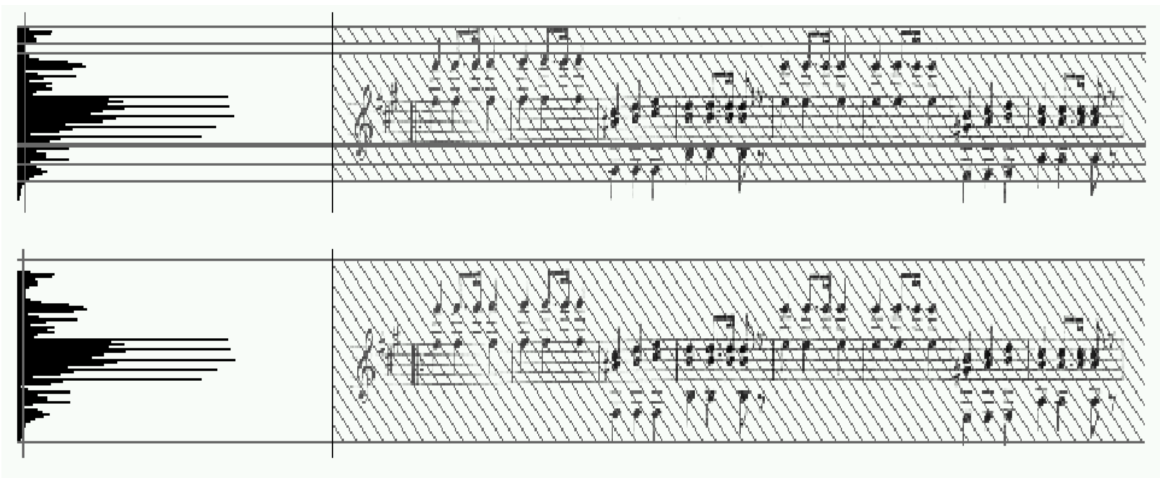

Fig. 13 - First phase: staff line detection

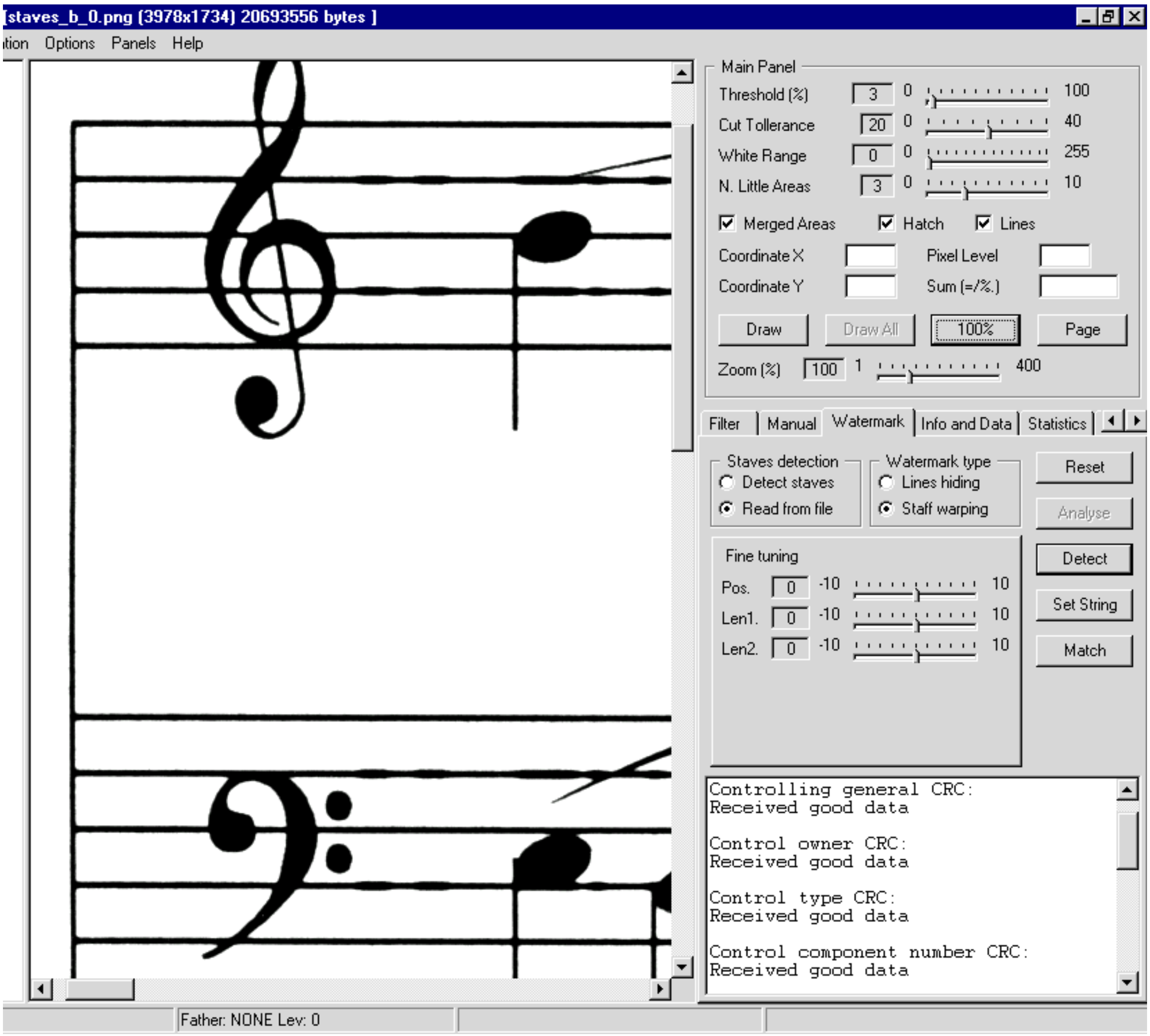

Fig. 14 - The screen shot of the watermark reading tool. The considered image was obtained after the acquisition of the original. In the bottom-right corner the CRC verification results are listed

Approach Validation

Our primary goal has been to embed a high number of bits to satisfy the user requirements. Obviously this constraint penalized some other aspects of the watermark requirements as the robustness.
Since an objective assessment was needed the validation of the method was performed in some meetings with several people working on music: the user group of expert of WEDELMUSIC project, plus other musicians of a local music school. The total validation has been based on the opinions of 28 people: musicians, copyists, publishers, computer music technicians and music teachers. Great part of the group were musicians, while only 4 were copy editors and 3 publishers.

The group was formed in this manner to cover the different needs. In fact, publishers have to accept to publish watermarked music. In turn, publishers use copy-editors, which are music engravers/copyists, for formatting music. Therefore, they are a very important category for the watermark validation. In general, it is possible to get a very good assessment from musicians. Obviously, 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.
We asked to assess a sequence of 15 different music scores. Some of them were watermarked others were not watermarked music sheets. Different watermark approaches were used for different music sheets. Different levels of photocopy of the same watermarked or not watermarked music sheets were included. Different resolutions of the same music sheets were also 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. It value has been chosen according to that most commonly used in printed sheets.

They were informed about the main concepts of watermark and not about the specific changes that we made on the music score. They performed the assessment singularly without the possibility to compare the different pages of music and the opinions of each other. After the assessment, we explained the techniques and we had a discussion. In the following only a part of the results obtained are reported. In most cases, during the assessment, the watermark was not detected from the participants in all music sheets in which it was present. Only after having informed them and explained how to see it, they were capable to detect it.

In Tab. 1, the results of the ITU results are reported. The mean vote is 3,45 that means a judgement between fair and good.

Ratin g	Quality	Number of answers	Percentage
5	Excellent	11	19,64%
4	Good	25	44,64%
3	Fair	4	7,14%
2	Poor	9	16.07%
1	Bad	7	12,5%

Tab. 1 - Results of the validation

Line Mask Approach

The watermarking approach proposed in this section can be applied at images of music sheet or during the printing of the music score from a symbolic music notation file. The approach consists on marking some points on the music score for virtually hiding a number of lines connecting them. A line based techniques for watermarking color images was presented in (Maes at al, 1998). The position and the orientation of the hidden lines are used as the vehicle to hide the watermark code. The first step in implementing such technique is to create a mask consisting in a number of lines (see Fig. 15). Each line angle encodes a number of bits.

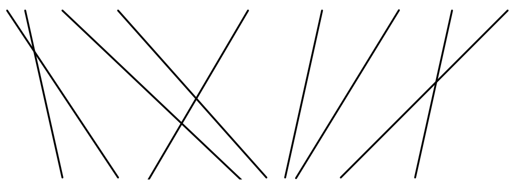

Fig. 15 - Line mask

In particular, the angle between the hidden line and the vertical axis has been used for hiding the information (see **Fig. 16**). The idea is not based on writing black lines on the music score (this may lead only to destroy the music sheet). The effective implementation consists in marking some points aligned to some hidden lines. The points that identify the hidden line may be placed in the intersection among the hidden line and the staff lines such as the points that in **Fig. 16** are marked with circles. In the solution taken, groups of the lines contributing to encoding the same code start from a common points.

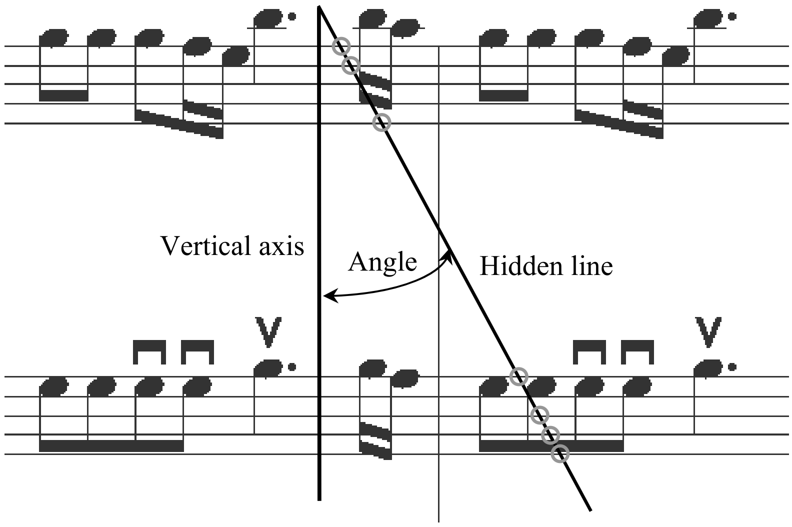

Fig. 16 - Possible points to be marked in the music score resulted after overlapping the hidden lines

The problems related to this approach are:

- The definition and identification of the starting point of the lines that encode the same code. The starting points have to be clearly identifiable.
- The identification of the vertical axis to estimate the angle.
- The identification of the hidden lines in the music score even when they are intersected each other.
- The estimation of the angle of the hidden line with respect to the reference vertical axis with a given precision.
- The insertion of a watermark comprised of at least 60 bits per page, considering that it has to be repeated several times on the page to make it robust enough for the reading.

Since the music scores may be deformed during successive photocopying some of the above problems have to cope with distortions during the watermark reading. The resulted points circled in **Fig. 16**, or only a part of them, have to be marked in some way. The intersection points located on the staff lines which are covered by other musical symbols have to be eliminated from the group of "markable" points. For marking points different techniques may be used (cutting the staff line with a white line, modifying staff line thickness, etc.) considering that the image score has to remain in two colors.

Fig. 17 - Watermarked music score

In **Fig. 17**, an example of the solution taken is presented. The marked points have been obtained by deleting a little part of staff lines. The inserted watermark is visible and absolutely not bother for the musicians. Please note that the real music score is normally smaller that the one depicted in **Fig. 17**.

In order to better retrieve the lines and to avoid false watermark detection the set of "markable" points has been divided in two subsets for any staff. The first contain the points on the first, third and fifth staff line, the second subset contain the points on the second and the fourth staff line (see Fig. 18). Between the possible 16 positions for the pairs we have used the first set and for the odds the second one.

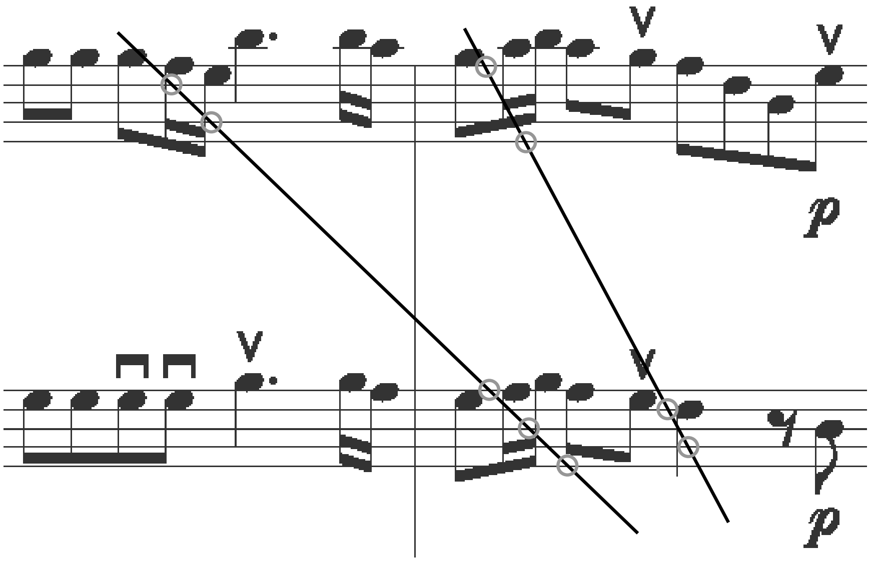

Fig. 18 - Points choosen to be marked in the music score

Embedding process

Once the approach was introduced some implementation details have to be exposed in follow.

Line mask definition

The line mask creation is the first step in the approach implementation. The code to be embedded has a total of 108 bits bits divided in three groups of 24 bits and a group of 36 bits (LDID). The angle of hidden lines has to be maintained in small range since the adoption of horizontal (or quite horizontal) lines leads to cut only few staffs and vertical lines may overlap barlines. If a line angle ranges from 3 degrees to 48 degrees then the line may assume 16 different positions to embed 4 bits. For hiding 24 bits, 6 lines are needed and for hiding 36 bits 9 lines are needed. Thus means that for the 108 bits 27 lines are totally needed. The lines were divided in four groups. The first group will be placed on the top left half page, the second on the top right half page, the third on the bottom left half page and the last on the bottom right of the page.   For the lines staying on the right side of the sheet the rules are the same but the angle will change from –3 degrees to –48 degrees.

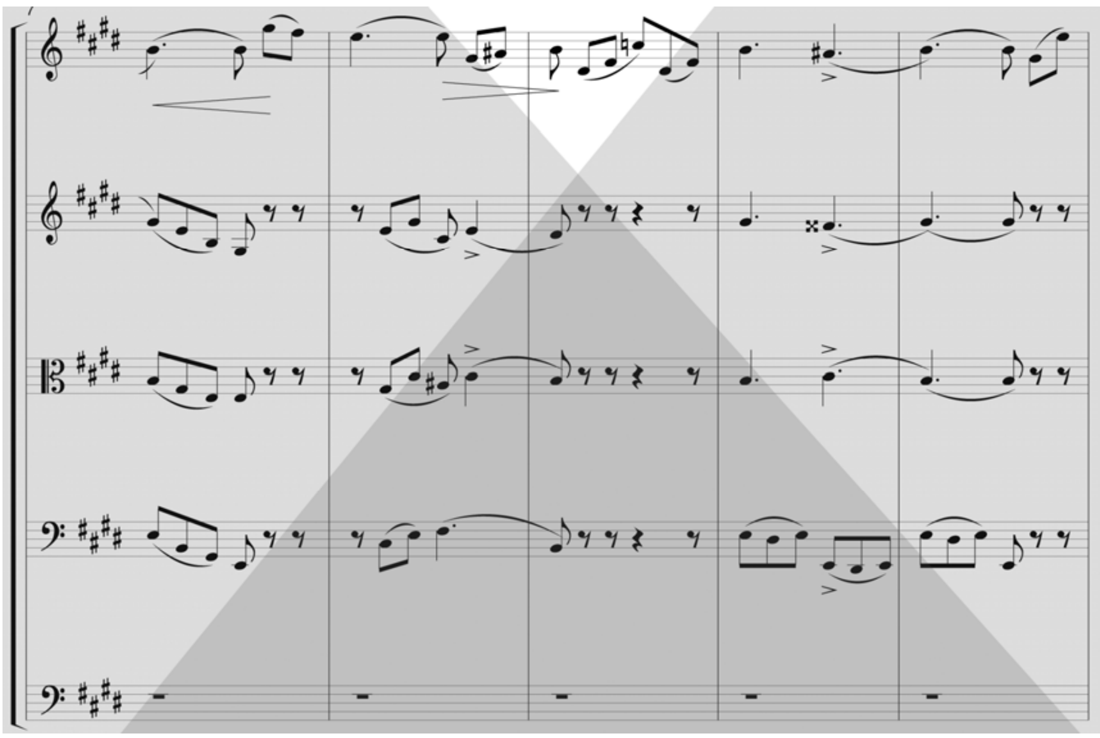

Fig. 19 - Lines angle variation depends on the line position

As shown in Fig. 19 the areas covered by the two sets of lines overlap in the middle bottom zone. Here some marked points belonging of both areas can be found. However, their alignment determines the right line. The area covered by the both sets of lines increases from top to bottom. If a little number of staves is used for hide a set of line it will be smaller. On the other hand, the code redundancy increases if more staves are used. At the final choice a compromise has to be accepted between the two parameters.

Starting Points
During the marking phase, the lines are placed over a block of staves, starting from fixed points on the first/second line of the first staff. This ensures the possibility to read watermark also if we are not capable to find the first marked point. The first (last) starting point is after (before) 1/100 of the staff length. The starting points of the hidden lines are spaced by 5/100 of the staff length. In our experiments, we have placed one half of hidden lines starting from the beginning of the staff to the middle. They have an angle oriented to the right-down side of the score page (as in the previous figures). The other half of the hidden lines, those that begin from the second half of the first staff line, are oriented on the opposite direction, left down. In this case, the hidden line direction is up towards the music staffs. A total of 20 hidden lines can be included.

Number and position of the marked points
During the watermark reading process finding the marked points means finding the lines and thus the watermarked code.

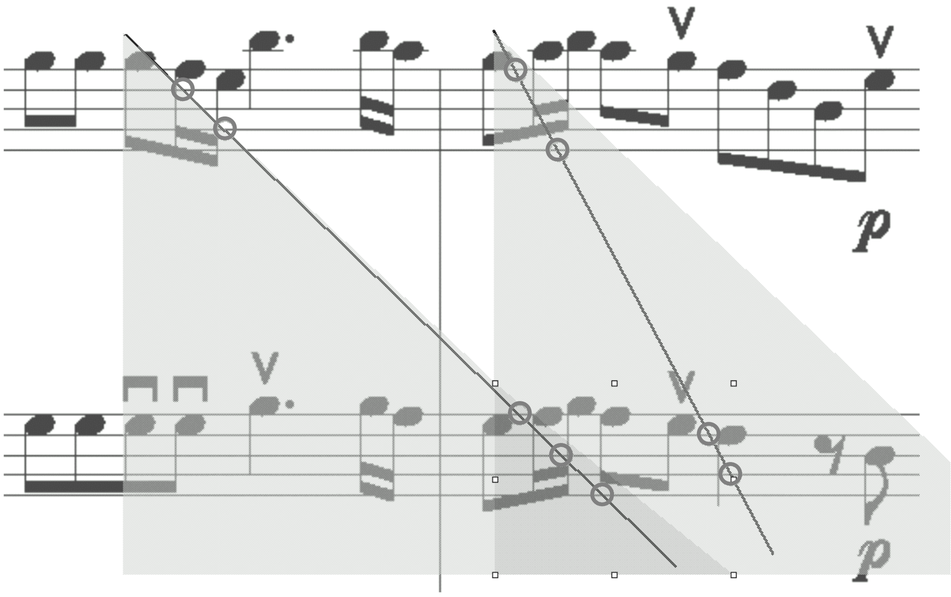

Fig. 20 - The areas where it is possible to find marked points are overlapped from the second staff.

In a given area, it is possible to find several marked points. That points should belong to the same line or not.
If it is supposed that the code is searched on 3 staves the next hypothesis can be considered:
- Each line marks 3 points on each staff;
- The areas covered by two successive lines are overlapped by 1/3 on the second staff and 1/2 on the third;
- The probability to find points belonging to other line (bad points) are P(1)=0 on the first staff, P(2)=0.4 on the second and P(3)=0.8 on the third.

That means that the mean value for the number of good points founded on a given area will be:

$$P_{GP}=3-P(1)*3+3-P(2)*3+3-P(3)*3=5.4 \text{ points}$$

Thus for each 9 searched points it is possible to find 3.6 wrong points.

Considering 3 staves the probability to find all 9 good points is:

$$P_{GP} = \frac{\text{number of good points}}{\text{total number of points}} = \frac{9}{9+3.6} = 0.714$$

If only two staves are considered the same probability will be:

$$P_{GP} = \frac{6}{6+1.2} = 0.83$$

since the mean value for the number of good points founded on a given area is

$$P_{GP}=3-P(1)*3+3-P(2)*3=4.8 \text{ points}$$

The founded values are quite good and can be subsequently increased if the point's alignment is considered. In order to eliminate some practical problem and increase the probability of true angle recognition other tricks can be used in the implementation phase.

If the problem of areas overlapping is considered than it is possible to change the marked points for two consecutive lines as shown in Fig. 20. In this case the problem is eliminated and for each set of points the line can be founded without problems.

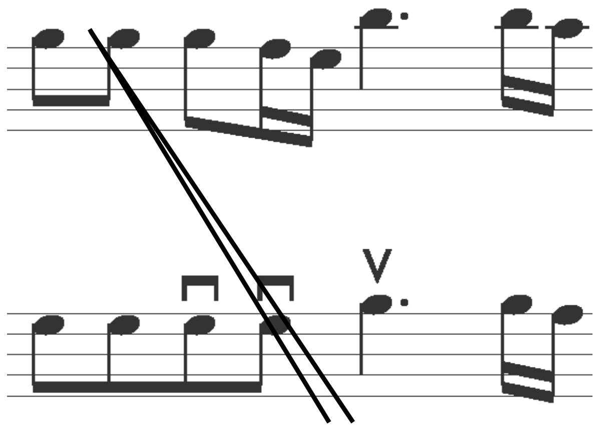

Fig. 21 – Two angles that differ by 3 degrees should be easily confused.

It is also possible to suppose to differently mark the points obtained from two successive angles. As it is easy to observe in **Fig. 21** two successive angles (the step between the angles is 3 degrees) of the same line.

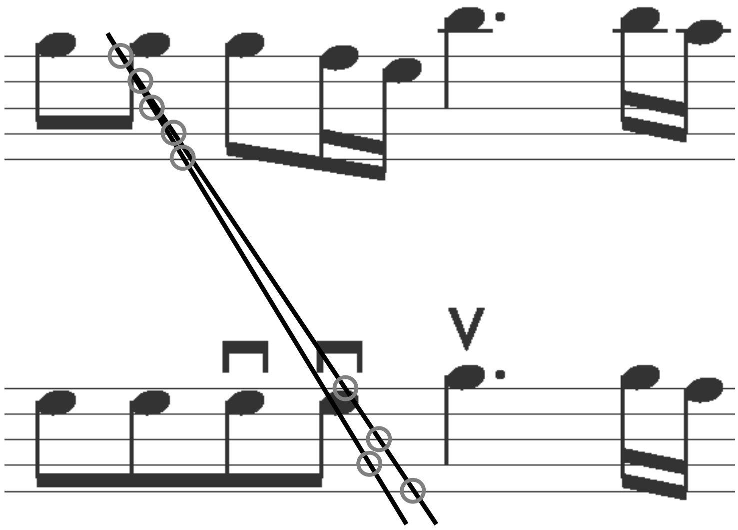

Fig. 22 - By differently marking the points for two successive angles the possibility to confuse is practically eliminate

Watermark reading

The process of watermark reading is mainly divided in five steps as reported in the following.

1. *Image segmentation.*

The image segmentation has basically the goal to detect the staff lines. It was already illustrated in the previous chapter where it was performed for the same purpose. The process is mainly composed by two phases:

- A first image scanning for estimates the distance between the lines and between the staves.
- A second scanning for finding 5 sequences of black pixels and 4 sequences of white pixel patterns with the previous determinate dimensions.

2. *Finding all reference points of the hidden lines over the staves.*

This is necessary to establish if a sufficient number of marked points exists in order to recognize the presence of not of the watermark. The number of points used is known on the basis of the algorithm parameters. The acceptance threshold is to detect the 40%-50% of points inserted during the marking phase. In order to find these points each staff line is scanned the vertical profile estimated. In order to search the reference points a sub-image window of dimension W x H has been used. The dimension H is 20% bigger than the staff line thickness. This depends on the resolution of acquisition and is dynamically determined. The dimension W is estimated by using a histogram-based approach (it is equal to the staff wideness) (Marinai at al, 1999). If E(x,y) is the image brightness gray level of pixel inside the scanning window, the V(x) profile is obtained as:

$$V(x) = \sum_{i=1}^{H} E(x,i), \qquad x = 1,2...W$$

The V(x) profile (see Fig. 23) presents some minimums where the staff line is interrupted even after several levels of photocopy. These minimums are the marked points of the hidden lines. The profile is processed with a low-pass filter to reduce the noise. Potential marked points of hidden lines are found when a given set of consecutive points of profile V(x) is under the threshold The threshold is 35%-40% of maximum V(x) value (the peak seen in Fig. 23 and 24 are not considered for the calculus of the maximum value). In Fig. 24, the histogram resulted after the analysis of the second photocopy is shown. The marked points can be easily found. In Fig. 24, the axis and the threshold level are shown. If $P_{cut(k)}$ are the points resulted at the intersection of t_s with V(x), (in Fig. 24 there are six *k* points), then the couple of $P_{cut(k)}$ and $P_{cut(k+1)}$ defines the x value where the marked point is found on the staff line.

$$\text{For each } x \in (P_{cut(k)}, P_{cut(k+1)}) \text{ will be } V(x) < t_s$$

where t_s at 40% from the maximum value of V(x) means that if the line thickness is 40% from the mean line thickness in that point a marked point will be considered.
The mean value is considered as the horizontal position of the correspondent marked point[1].

$$x_{mp(\frac{k+1}{2})} = \frac{P_{cut(k)} + P_{cut(k+1)}}{2}$$

3. Finding the starting points of each line.

On the basis of the above described mechanism for positioning the starting points, they are searched at the calculated position for the specific staff line (first or second staff line) from which the hidden line is supposed to begin. The processes of photocopy and image acquisition by means of scanner introduce horizontal distortions. To cope with this problem a quite large tolerance is used. If the starting point are missing, the lines could be recovered by using a combinatorial Hough transform working on points detected on the image (Nesi at al. 1995).

4. Finding the points matching the lines.

For each starting point and for a fixed set of possible line slopes the detected potential marked points identified at the first step are verified. The potential marked points considered are those located inside an image transversal scanning segment (see **Fig. 26**), placed over the staves, for each given slope of the hidden line[2]. This ensures to examine only a few points near to the line and at the same time, to compensate distortions.

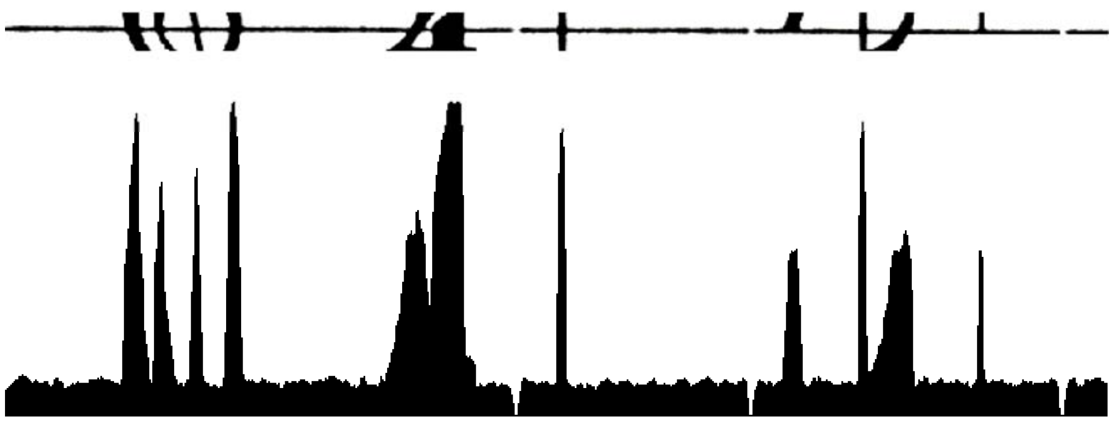

Fig. 23 - Horizontal histogram of a staff line segment.
The white hole corresponde to the marked points.

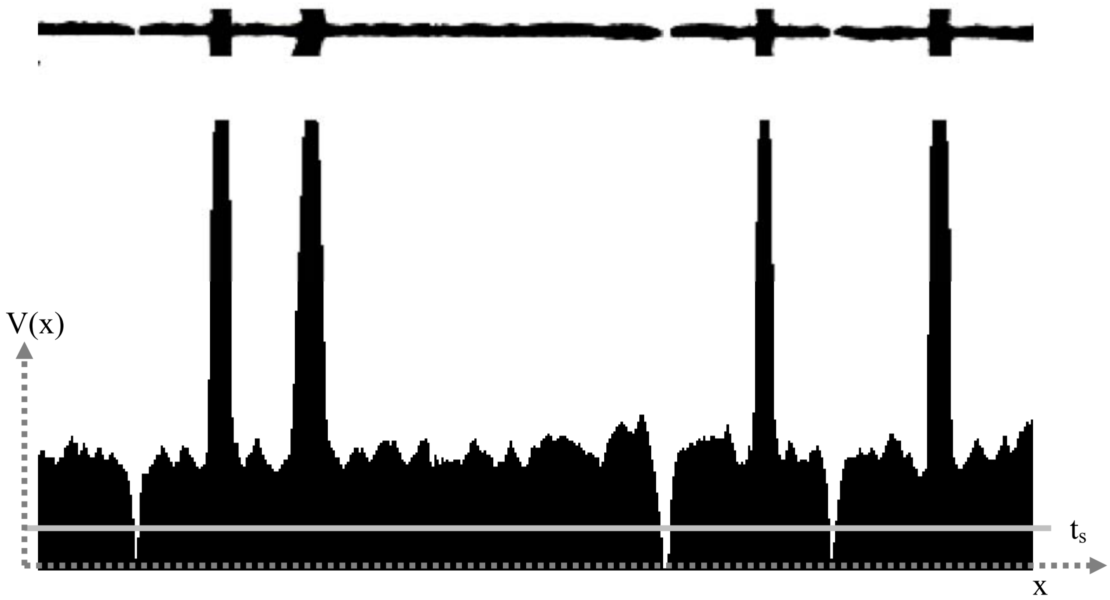

Fig. 24 - The same histogram performed on a image obtained from the second photocopy. The line thickness increase, some points are difficulty visible on the line but the histogram allow their exact determination. On the images the horizontal and vertical axis and the threshold level are shown

The gray image segment highlighted in **Fig. 26** has an angle α corresponding to the searched bit sequence and the thickness *w.* The thickness is used as a parameter and may vary from three to ten pixels. The angle may vary between 3 and 48 degrees.
If x_i and y_i are the coordinates of the $N_{\alpha k}$ points (named P_i) founded into the gray window then the line will be determined by y=ax+b. The points inide the scanning segment are considered in order to estimate the slope, *a*, of the hidden line. To calculate *a* the next formula can be used:

$$a = \frac{N_{\alpha k}\sum_{i=0}^{N_{\alpha k}} x_i y_i - \sum_{i=0}^{N_{\alpha k}} x_i \sum_{i=0}^{N_{\alpha k}} y_i}{N_{\alpha k}\sum_{i=0}^{N_{\alpha k}} x_i^2 - \left(N_{\alpha k}\sum_{i=0}^{N_{\alpha k}} x_i\right)^2}$$

Unfortunately the previous formula does not give the expected result in practice since the number of used point ($N_{\alpha k}$) is too low. The slope and its variance are estimated, in reading the watermark, by using each possible couple of points such as in (Nesi at al. 1005).
With $N_{\alpha k}$ points,

$$N_{\alpha x} = \frac{N_{\alpha k} * (N_{\alpha k} - 1)}{2}$$

combinations of two points (P_i and P_j with $i \neq j$) are possible.
For each line (build with the two points) the slope is calculated. This slope is subject to distortion so a threshold of 1 degree is accepted. In Fig. 25, the distribution of the couples of points angle is shown. Reading the watermark from the original printed music score give no problems in identification of the right slope were detected.

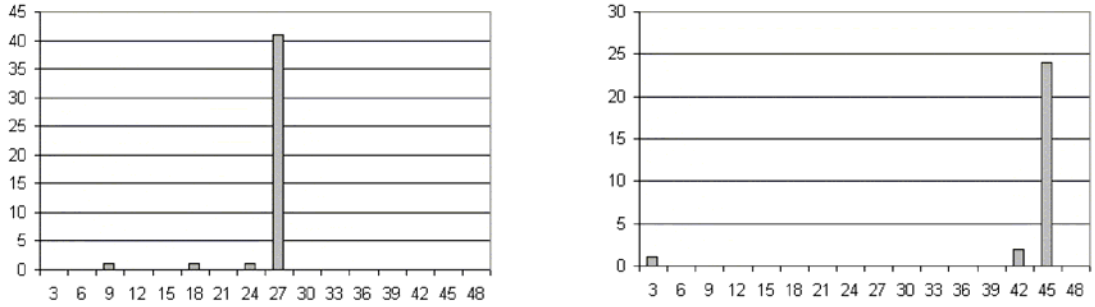

Fig. 25 - The number of points founded in a couple of windows angled at 27 and 45 degrees respectively.

The obtained most likelihood slope is accepted if:

- the number of detected potential points is higher than a predefined threshold,
- the value is close to the reference value of the scanning segment,
- the variance is lower than a predefined threshold, and
- the distribution can be considered Gaussian (to this end a statistic test is performed).

Considering 9 good points and 3.6 wrong points for 3 staves the good combination of couple of points is:

$$C_{GP} = \frac{N_{GP}(N_{GP}-1)}{2} = \frac{9*8}{2} = 36$$

The combinations of wrong points will be

$$C_{WP} = \frac{N_{WP}(N_{WP}-1)}{2} = \frac{4*3}{2} = 6$$

$$P_{GP} = \frac{\text{number of good comb.}}{\text{number of total comb.}} = \frac{36}{36+6} = 0.837$$

The combinations of mixed points were not considered since it can be easily eliminated by considering their alignments. For only two staves, with 6 good points and 1.2 wrong points the probability is 0.937. Both the probabilities are greater with respect the normal ones.
If false point and missed detections are considered it is possible to suppose that:

$$N_{fc} = K_{fc} * N_w$$

and

$$N_{ff} = K_{ff} * N_g$$

Where:

- N_{fc}, number of false cuts;
- N_{ff}, number of missed point detection (fully false points);
- N_w, number of wrong points (real marked points from other hidden line);
- N_g, number of good points (marked point of the searched hidden line);
- K_{fc}, the probability to have false cuts;
- K_{ff}, the probability to have false full.

It is reasonable to suppose that Nw=Ng*0.3 (since two successive zones may overlap by 1/3 on the second staff). K_{fc} is really small than 10% and K_{ff} should be supposed to be around 20%.

In this case the probability to have good line angle estimation can be calculated as:

$$P = \frac{N_g - N_g * K_{ff}}{N_w + N_w * K_{fc} + N_g - N_g * K_{ff}} = \frac{N_g\left(1 - K_{ff}\right)}{N_w\left(1 + K_{fc}\right) + N_g\left(1 - K_{ff}\right)}$$

replacing K_{ff}, K_{fc} and N_g in the previous formula the P value can be calculated to be:

$$P = \frac{N_g\left(1 - K_{ff}\right)}{N_w\left(1 + K_{fc}\right) + N_g\left(1 - K_{ff}\right)} = \frac{N_g\left(1 - K_{ff}\right)}{N_g * 0.3 * \left(1 + K_{fc}\right) + N_g\left(1 - K_{ff}\right)} =$$

$$\frac{1 - 0.2}{0.3 * \left(1 + 0.1\right) + 1 - 0.2} = \frac{0.8}{1.13} = 0.707$$

This means that also if a reasonable probability of false detection is considered the probability to perform good angle estimation remain at acceptable level.

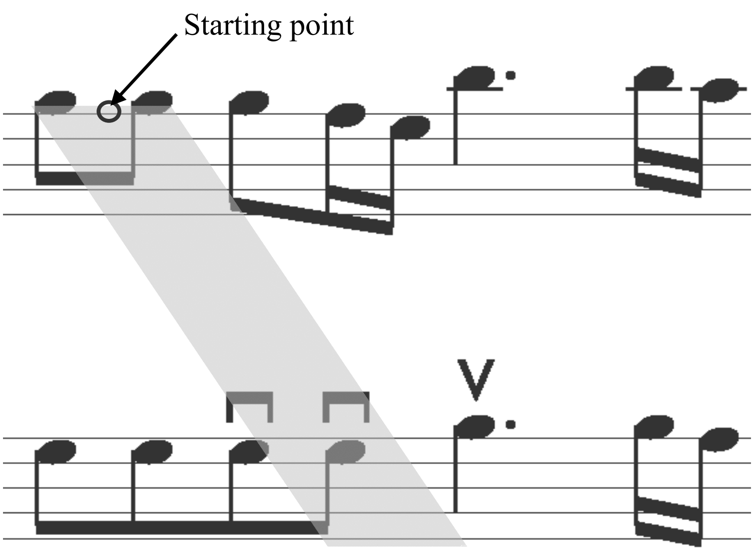

Fig. 26 - The scanning window for watermark reader in case of forensic detection. The gray zone is scanned for marked points.

5. Watermark code reconstruction

This is the last step of the reading process. The code will have N blocks of 4 bits if N is the number of hidden lines. The angle of each line determines the value of respective blocks.

$$b_k = \frac{\alpha_k - 3}{3}$$

where α_k is the angle of the line k and b_k is a number between 0 and 15 thus a sequence of 4 bits.

Notes

The approach may be used also in case of blind detection. The blind detection means to start scanning the image without previously knowing the line angle. The watermark reader have to consider all the points found in the area and then trying to determine the most probable angle. The difference is that the scanning window has to be greater than the precise one in order to cover all the possible positions where marked points should be founded (see Fig. 27). The previous calculated probability is referred to this case since the probability of zone overlapping was considered as 1/3 for the second staff and 1/2 for the third staff (see also Fig. 20).

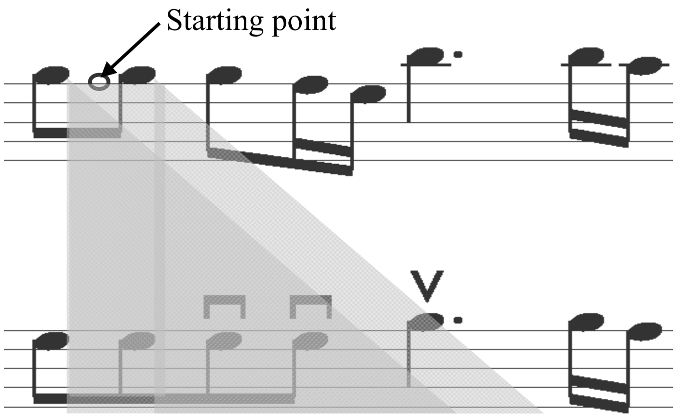

Fig. 27 - The scanning window for watermark reader in case of blind detection. The gray zone is scanned for marked points.

Mask Approach Validation

Our primary goal has been to embed a sufficient number of bits to satisfy the user requirements. This constraint penalized a bit the robustness since the total number of embeddable bit is limited. The first step to be performed for the validation has been to evaluate the quality of the printed watermarked music sheets by using a scale as the one presented in (Kutter and Peticolas, 1999), based on the Human Visual System.

The presented technique was validated by the previously described user group of WEDELMUSIC project. For the validation we asked at the user group members to assess a sequence of 15 different music scores and only 5 of them were watermarked. In most cases, during the assessment, the watermark was not detected from the participants in all music sheets in which it was present. Only after having informed them and explained how to see it, they were capable to detect it. In Tab.2, the results of the analysis are reported. The mean vote is 3,71 that means a judgement between fair and good.

Rating	Quality	Number of answers	Percentage
5	Excellent	6	10,71%
4	Good	29	51,78%
3	Fair	9	16,07%
2	Poor	6	10.71%
1	Bad	0	0%

Tab.2 - Results of the ITU validation

After to obtain the end-users' acceptance of the watermark solution we have tested the watermark robustness against several levels of photocopying. The results were encouraging the watermark can be easily read after 5 levels of photocopying. The robustness mostly depends on the technique used for marking points.

Non Watermark-based Approach for Music Sheet Protection

During the research performed for watermarking techniques a different approach for copy control was analyzed.
The problem is to find something that disables the music sheets photocopying. A solution can be to find something that when the music is photocopied act as a content destroyer.
No solution seems to offer this capability since the photocopying machine act as a passive instrument.

It is known that adding yellow lines on a page the black and white photocopy hardware will transform the yellow lines in dark gray. The idea to add yellow shape on the music sheet is not suitable since the printing is normally performed on black and white printer and the yellow share will be loosed.

The idea should be to add some light gray shapes. Some tries were performed by adding a light gray rectangle around the music as a kind of background (see Fig. 28).

Fig. 28 - Music printed on a light gray background

The quality of the photocopied music sheet decreases very rapidly and at the third level of photocopy the music sheet is almost no more readable.

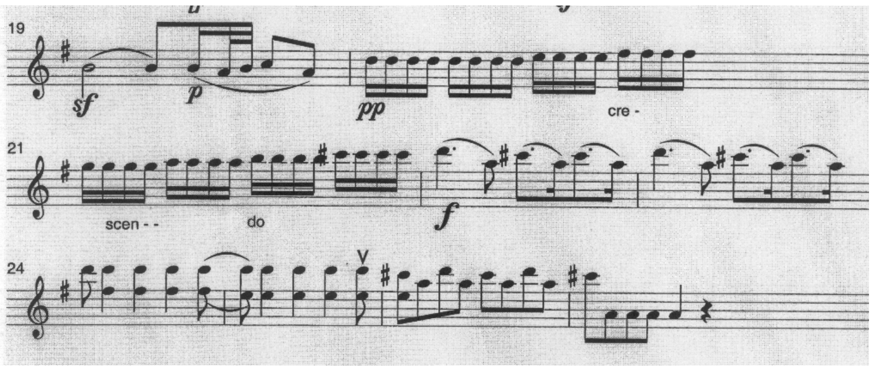

Fig. 29 - The music sheet after the first photocopy

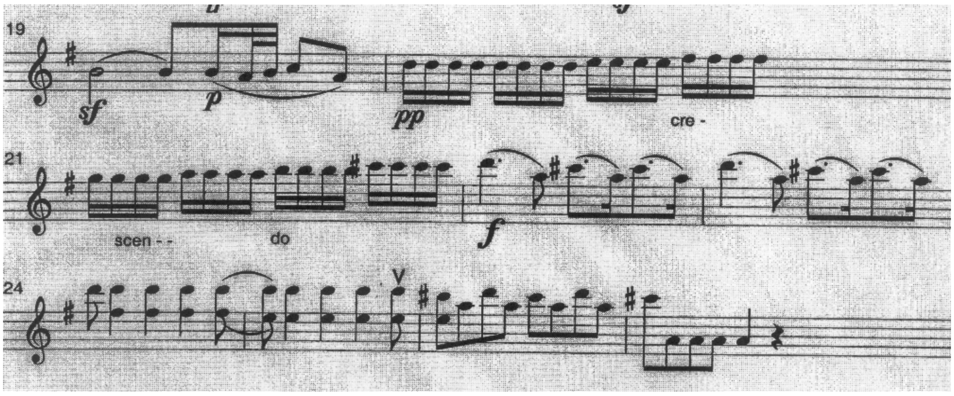

Fig. 30 - The music sheet after the second photocopy

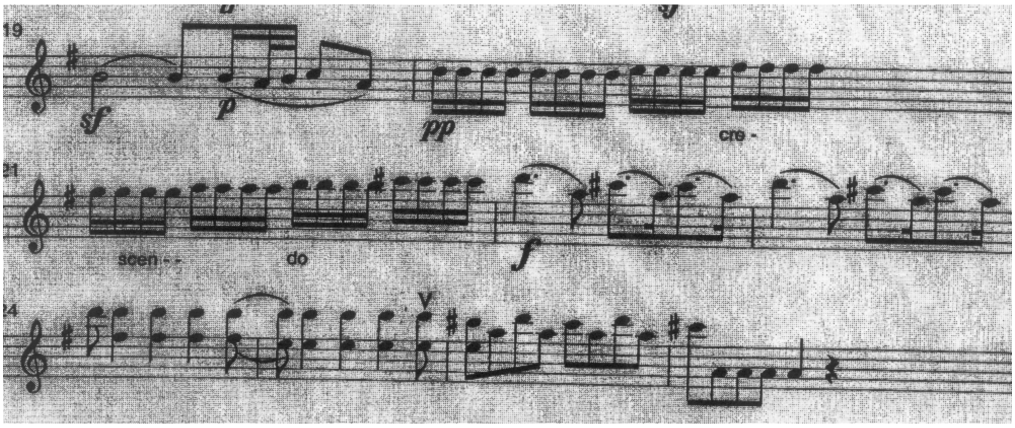

Fig. 31 -The music sheet after the third photocopy.
The originally light gray pixels change to a dark gray
color and the music became no more readable

It is interesting to observe how the areas more rich (dense) in symbols are the first to loose readability. The result seems to offer a future field of investigation in music sheet copy control.

CONCLUSIONS AND FUTURE TRENDS

The protection of music sheets is very important since they are entering in the digital market and distribution. The watermark of music sheets is a new area of research and new solutions and algorithms are expected. The main problems are related to the fact that music is mainly black and white information while great part of the techniques adopted for images are based on the presence of colors. The music sheet watermarking can be also considered a good way to understand when the music sheet has been non legally copied rather than to be capable to demonstrate the violation of copy right. In fact, the copyright for the music sheet is in several cases related to the visual shape of the music, that is the music formatting of music.

Recently, some optical music recognition, OMR, systems have been proposed. They can be considered killer applications for the music sheet watermarking as the OCR for textual watermarking. On the other hand, the quality of OMR systems is not presently satisfactory to be considered a real risk for music sheet watermarking technologies.

As shown in the chapter, some of the techniques proposed are strong enough to provide watermarks that persist after a significant number of photocopy levels. When the degradation of the photocopy process has reduced the quality and thus the value of the music sheet the watermarking can be lost but not before. This is extremely promising for the publishers.

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[1] The vertical position of the marked points results from image segmentation phase

[2] During watermark reading, the estimation of the vertical axis orientation is performed on the basis of the location of the staff barlines (vertical lines separating measures).