



The Interactive-Music Network

DE4.7.1

CIMS: Coding Images of Music Sheets

Version: 2.2

Date: 03/02/04

Responsible: UNIVLEEDS

Project Number: IST-2001-37168
Project Title: The Interactive-Music Network
Deliverable Type: Doc./HTML
Visible to the Working Groups: yes
Visible to the Public: yes

Deliverable Number: DE4.7.1
Contractual Date of Delivery: M18
Actual Date of Delivery: 03-02-2004
Title of Deliverable: CIMS: Coding Images of Music Sheets
Work-Package contributing to the Deliverable: WP4
Nature of the Deliverable: Public
Working Group: CIMS (Music Imaging WG)
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Abstract:

This document reports the applications and practices in the domain of coding images of music sheets (music imaging), which include music sheet digitisation, recognition, restoration, and others. It reports hardware and software related to music imaging, with discussions on main obstacles and approaches to evaluate state of the art OMR system.

Keyword List:

Music imaging, music digitisation, sheet music, image processing, scanner, optical music recognition, OMR, optical music restoration, multimedia, image

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1 Executive Summary and Report Scope

This document reports the applications and practices in the domain of coding images of music sheets (music imaging), which include music sheet digitisation, optical music recognition (OMR) and optical music restoration.

With a general background of Optical Music Recognition (OMR), the report discusses typical obstacles in this domain and reports currently available commercial OMR software. It reports hardware and software related to music imaging and discusses steps required to evaluate the state of the art OMR system.

Besides the main focus on the transformation from images of music scores to symbolic format (for printed and handwritten music notation), this document also reports music image restoration and the application of music imaging techniques for graphical preservation and potential applications for cross-media integration.

2 Introduction

The document explore issues on the digitisation, restoration and automatic transcription of music documents; converting paper-based music document into machine readable formats, in order to explore effective use of the latest interactive and multimedia technologies for cultural heritage restoration and preservation of musical documents, such as printed music scores, handwritten manuscripts and ancient music scores.

With the advancements of digitisation and information technologies, document analysis and optical character recognition technologies are now widely used, from form processing to handwritten address recognitions. As we know, document imaging, analysis and understanding is extremely complex, not to mention the additional complexities inherent to Music notation.

There are a vast amount of invaluable paper-based heritage, including printed music scores and handwritten manuscripts, that are deteriorating over time due to natural decaying of paper and chemical reaction (e.g. printing ink and paper), similar to many other paper-based items in library and museum archives. In order to introduce interactive multimedia music capabilities and functionalities, machine readable representation is required, and hence one of the main steps is to create digital version of these paper-based heritage materials for further processing (restoration, encoding, recognition etc) in order to allow long term preservation and wider and more effective distributions. Various efforts have been focused on this issue in order to preserve the record of our heritage. For example, manual and highly skill *paper-splitting* technique used to conserve Bach's manuscripts [Porck & Teygeler, 2000; Wächter et al., 1996].

3 Background

Digitisation has been commonly used as a possible tool for preservation. Although the digital copy may not conserve the original document, it can preserve the data in the document, with the advantage of easy duplications, distribution and digital processing.

Optical Music Recognition (OMR), also commonly known as OCR for Music (Optical Character Recognition for Music) was first attempted in the 60s, and since then there have been a wide range of research and developments in this interdisciplinary domain. Currently there are various commercially available products as well as research systems for OMR. OMR system transforms paper-based printed music scores and handwritten music manuscripts, into a machine-readable symbolic format, and an optical music restoration system to reconstruct small discontinuities and imperfection in the musical writings, including broken stems and stave lines. An idealise system which could reliably “read” and “understand” music notations could provide a wide range of applications for interactive multimedia music, bringing paper-based music to the new multimedia era.

OMR was first attempted over thirty years ago [Pruslin, 1966]. It has received much attention over the last fifteen years [Bainbridge & Wijaya, 1999; Bellini et al., 2001; Bruno & Nesi 2002; Ng & Boyle, 1992; Ng, 1995; Ng et al., 1999; Ng, 2002; etc, see Section “OMR Bibliography”], and there are currently a number of commercially available packages, such as capella-scan [capella-scan], Optical Music easy Reader [OMeR], PhotoScore [PhotoScore], SharpEye [SharpEye], SmartScore [SmartScore] and Vivaldi Scan [Vivaldi Scan].

However there are still much room for improvements in many aspects. Reviews and background on the development of various OMR systems can be found in Bainbridge & Carter [1997], Blostein & Baird [1992] and Selfridge-Field [1994]. An online bibliography on OMR can be found at the Interactive MUSICNETWORK website (<http://www.interactiveMUSICNETWORK.org>) and <http://www.kcng.org/omrbib/>

4 Obstacles, Music Notation

Optical Character Recognition (OCR) is perhaps the best known related document image processing problem, but OMR can be critically different. The visual problem might seem simple since writing is normally black on white paper. However, OMR introduces an additional layer of complexity due to the wide range of possible shape variation resulted from inter-connections and groupings of symbols. Furthermore there may be other symbols (e.g. expressive signs, fingerings, bowing, texts, etc.) that are positioned around and sometime overlaid part other music symbols. For example, a tie crossing a stem or touching a note-head.

Music Notation is inherently opened ended. Even if generally considered as stable for the period of XVIIIth and XIXth centuries in the Western world, there are several exceptions, such as “unmeasured notation” (for cadenzas and so on), approximate rhythmic notation (several examples can be found in works of authors like Chopin, Schumann or Mendelssohn), or slight enhancements to traditional notation (slurs without ending note, non canonical time signatures...). In the earlier centuries, with neumatic or Gregorian notation, music notation was very far of a standardized system, and in the XXth century, music notation has exploded, and is noticeably far from that model commonly known as Common Western Music Notation.

Direct recognition of musical symbols is difficult due to the design of the notation. In general, OMR system uses divide-and-conquer approaches to separate musical features before recognition. For example, stave lines are detected and marked before/after note-head in order to separate one feature from the other.

Basic musical syntax (e.g. time-signature) and domain-knowledge enhancement such as rhythmical analysis have been explored to improve recognition performance. Fahmy & Blostein [1998, 1994] propose a graph-rewriting approach for OMR enhancement. Stückelberg et al. [1997] propose an architecture for OMR with high-level domain knowledge and Stückelberg & Doermann [1999] explore probabilistic reasoning for musical score recognition. Coüasnon [2002] comments that existing OMR software is not suitable for industrial context due to time consuming and tedious manual proof reading, and proposes a system that is capable of self-diagnostic to detect error [Coüasnon and Rétif, 1995]. The paper discusses the application of musical knowledge of music writing to enhance OMR processing and recognition using DMOS (Description of MODification of Segmentation), a generic recognition approach for structured document analysis with grammatical formalism EPF (Enhanced Position Formalism).

5 Music Digitisation

5.1 Hardware

Nowadays, document digitisation systems such as optical flatbed scanners are widely available. There are a wide range of commercial products from manufacturers such as Fujitsu, Agfa, HP, Cannon, Epson, UMAX, Microtek, Visioneer and many more. Currently available commercial products are equipped with USB, parallel or SCSI interfaces. Some of these products support dual-interfaces.

Many of these products are capable of more than 600 d.p.i. (dot per inch) optical scan resolution with grey or up to 48-bit colour depth which surplus general requirement for OMR processing.

Increasingly digital photo-copiers are also equipped with optical scanner which provides high-speed digitisation. Examples include products from Ricoh and Canon.

Drum scanners are less commonly being used in this domain. Besides professional flatbed scanners (such as Creo Scitex, Heidelberg and others), industrial music imaging applications for archiving (bitmap images) also use a digital-camera-back or digital-camera with a copy-stand setup which range from a simply board for document placement to include fully pneumatically controlled book cradle system as well as complex robotic control automatic page-turning system. Examples of overhead-scanning products include:

| Company | Product | Notes | URL |
|---------------------------------|--|--|---|
| Kirtas Technologies, Inc. (USA) | APT BookScan 1200 | World's first automatic book scanner | http://www.kirtas-tech.com |
| 4DigitalBooks | "DIGITIZING LINE" | Automatic digitizing system | http://www.4digitalbooks.com |
| Zeutschel GmbH | various MONISCAN models | Large format colour scanner OMNISCAN9000 | http://www.zeutschel.de |
| Solar Imaging Systems, UK | M3 & M5 digital camera systems | Maximum optical resolution 8192x12000 pixels | http://www.solar-imaging.com |
| Icam Archive Systems, UK | GUARDIAN | Various models including Guardian which uses Phase One camera backs | http://www.icamarchive.co.uk |
| Konica Minolta | Minolta PS7000 book scanner | up to A2, 256 greyscales | http://www.minoltaeurope.com/... |
| InfoSys GmbH | alpha librae | up to 900 pp/hour, greyscale & colour model | http://www.infosys-scanner.de/indexE.html |
| ImageWare Components GmbH | Bookeye products | Oversize formats up to 350 x 720 x 470 mm | http://www.bookeye.com |
| Imaging Business Solutions | SMA ScanFox | A1 and A2 | http://www.imagingbusiness.co.uk |
| Lumiere Technology | Jumbo Scan | 30000x12000 pixels | http://www.jumboscan.com/ |
| Cruse Digital Equipment | Various models including Synchron Table Scanners | CS 175P which accepts originals as large as 40"x60" | http://www.crusedigital.com/scanners.html |
| Zeutschel GmbH | Zeutschel Omniscan 10000 | Bbooks, newspapers and large format documents (maps, drawings, posters) 871x 610 mm (A1) = 10424x 7300 pixels and 24 bit/pixel | http://www.zeutschel.de |

With increasing pixel count, one-shot digital camera systems are increasingly usable for this domain. For examples:

- PhaseOne, www.phaseone.com
- BetterLight, www.betterlight.com
- Imacon, www.imacon.dk
- Fujitsu, <http://www.fujitsu.com> and
- others

With high-end digital camera or scan-backs system, copy-stand is necessary. Examples of copy-stand include:

- Bencher, <http://www.bencher.com/copystands.html>
- Beseler, http://www.beselerphoto.com/Product_Catalog/o1.pdf
- Kaiser, <http://www.kaiser-fototechnik.de>
- Linhof, <http://www.linhof.de/english/zubehor/repro/repro.html>
- Testrite, <http://www.testrite.com/CopyStands.htm>
- Tarsia Technical Industries, <http://www.ttind.com>

5.2 Digitisation

There are many digitisation related projects and institutions which have produced good set of guidelines or publications related to these issues. These include:

- MINERVA, <http://www.minervaeurope.org>
- PULMAN, <http://www.pulmanweb.org>
- AHDS (Arts and Humanities Data Service), UK, <http://www.ahds.ac.uk>
- British Library, <http://www.bl.uk/services/preservation/freeandpaid.html>
- CLIR (Council on Libraries and Information Resources), *Building and sustaining digital collections: models for libraries and archives*, <http://www.clir.org>
- DLF (Digital Library Federation), *Digital library standards and practices*, <http://www.diglib.org/standards.htm>
- Library of Congress, A Framework of Guidance for Building Good Digital Collections , <http://www.nap.edu/catalog/9940.html>
- UNESCO/ICA/IFLA, Guidelines for digitization projects for collection and holdings in the public domain, particularly those held by libraries and archives <http://www.ifla.org/VII/s19/pubs/digit-guide.pdf>
- DI.MU.SE project (*Ministero per i Beni e le Attività Culturali* and Palatina Library of Parma) provided guidelines for the digitalisation of 150.000 music manuscript pages. <http://www.bibpal.unipr.it>
- and others

As with other document imaging processes such as Optical Character Recognition (OCR), OMR is not particularly demanding on currently available optical document scanners. Typically, for sheet music, 300 d.p.i optical resolution and 8-bit grey is sufficient for the purpose of OMR [Selfridge-Field 1994]. Fujinaga & Riley (2002) reported that 600dpi is a sufficient resolution for all significant details. The paper suggested that further increase in resolution is not necessary for OMR. Generally, the first process in a document analysis system is to threshold a given grey input image into a binary image. Some systems used binary input images produced by the digitiser.

Regarding the Italian DI.MU.SE project, the digitalisation parameters for the music manuscript was fixed for the master copy in 300 d.p.i optical resolution with colour depth at 24 bit RGB, TIFF format.

6 OMR

6.1 Commercial OMR Systems

Current, there is a number of commercially available OMR software. No comprehensive comparative study has been carried out, and hence this is urgently required. In order to provide unambiguous comparative study between different software, terminology for all musical primitives (e.g. note-head, stem, etc) has to be standardise. For a non-bias survey of OMR software, a representative and sufficiently large ground-truth dataset of music sheets containing different style of fonts, density, sizes and page layout has to be collected. Simple recognition rate (as in Optical Character Recognition) does not offer good/meaningful measure for OMR system due mainly to the complex musical notation which may change (visually) depending on the contexts, and hence a good assessment matrix is require to provide meaningful assessment for OMR system. Current proposal include a 3 level approach with measurement at primitive-level, note-level and interpretation- (score-) level.

Commercially available OMR systems include:

- capella-scan
- Optical Music easy Reader (OMeR)
- SharpEyeMusic Reader
- SmartScore
- Neuratron, PhotoScore

- BraeburnSoftware, Music Publisher system
- Vivaldi Scan (derived from SharpEye)
- Musitek, SmartScore
- Scorscan of NPCImaging <http://www.npcimaging.com/scscinfo/scscinfo.html>
- MIDI-Connections Scan, http://www.midi-connections.com/Product_Scan.htm

7 OMR Evaluation

7.1 Obstacles

The Optical Music Recognition task is more complex than OCR. Despite to the availability of several commercial OMRs: SharpEye2, SmartScore, Photoscore, CapellaScan, etc., none of these is satisfactory in terms of precision and reliability. The efficiency declared by the each distributor is close to 90%, but this value is obtained only when quite regular music sheets are processed and the estimation is not always objective. In the character or face recognition field, there are many ground truth databases that enable recognition results to be evaluated automatically and objectively. At the present time, there is neither a standard database for music score recognition or a standard terminology. If a new recognition algorithm or system were proposed, it could not be compared with the other algorithms or systems since the results would have to be traditionally evaluated with different scores and different methods. Taking these facts into consideration, it is indispensable to make a master music score database that can be used to objectively and automatically evaluate the music score recognition system. At the same time a set of rules and metrics are needed in order to define what aspects have to be considered in the evaluation.

In general, the currently available commercial OMR systems are linked to a music notational software. For example, PhotoScore outputs directly into Sibelius. It is not easy to access the performance of the OMR system alone without interaction with the interface provided by the notational software. That is to say, it is not always possible to output from the OMR system itself. This problem is even complicated by the lack of a commonly accepted standard for musical notation.

All the currently available OMR systems offer capture facilities to communicate directly with the scanner. This is another complication since it is not easy to make sure that the inputted images for all OMR systems are exactly the same (pixel perfect). For the OMR assessment, file input is clearly preferred, however the complications here include:

- different input format support
- different optimum resolution
- different image depth requirement (e.g. 2-bit, 8-bit etc.) and different pre-processing approaches.

Besides differences of input and format representation, differences in output formats, due to the lack of a commonly accepted standard for musical notation, present another layer of complication. Generally output can only be obtained in the proprietary format of the music notation software – that is, the “.mus” or the Enigma format for the Finale software, the Sibelius format for the Sibelius software, and so on. Some of these formats, such as the “.mus” format, are undocumented, and some partially documented format such as the Enigma format are perpetually evolving and suffering of lacks of documentation.

The NIFF format, which was designed at the very origin for the purpose of exchanging music notation between different music notation software, noticeably OMR and music notation software, is now used by very few notation software (see the MUSICNETWORK deliverable DE4.1.1, “music notation coding”), and some OMR software are not able to export in this format.

In general, all music notation software could export in the MIDI format, but this format doesn’t capture all features of music notation, thus that format can be used only in a first approach. Noticeably, the MIDI format doesn’t capture rhythmic features, and output in MIDI from different music notation software could be slightly different depending on the music software. It would however be possible to set up a methodology based on the MIDI format, with a first step of export in MIDI, followed by an import in a reference software.

It is not easy to compare results outputted in different formats due to their individual designs and capabilities. Due to these complications, “scan once, use many” methodology may not be easily applied.

Moreover, complexity of music notation is a supplementary challenge: the fundamental unit of music notation (the note) is itself a complex object, made of a note head, a stem, a flag or a beam, possibly an accidental and dynamic markings such as staccato dot. This complex object can be modified in its fundamental meaning - pitch and duration - by its environment (clef, key signature, time signature...). The results of the comparison can be distorted by errors in context which cannot be taken in account by the comparison test himself (tempo marking). Thus, a good methodology for comparing results must involve definition of different ratios for each kind of error, and is to be taken into account in the methodology definition. An error of clef, for example, would produce an error for each note in the MIDI output, while being easily corrected by just one correction in the notation format. These errors must be corrected at the earliest step possible, since errors done could induce bad corrections and artefacts introduced by software at a later step (for example, error in time signature could introduce completion of measures in notation software, by introduction of incorrect rests for completion of measures). In the same manner, a normalisation must be done at an earlier stage to correct possible errors of non-significant features such as tempo markings which could introduce differences in the final output.

A proposed methodology for comparing OMR software would then involve the following steps:

1. Input of scan with different resolutions, different format support, different image depth
2. First step of correction for context errors: clef, time signature, key signature.
3. Normalization of context for non tested features: tempo marking
4. Output in music notation software
5. Second step of correction for context errors: clef, time signature, key signature (if not possible at an earlier stage)
6. Normalization of context for non tested features: tempo marking (if not possible at an earlier stage)
7. MIDI export
8. MIDI import in a reference software – Normalization of context (tempo markings – dynamics – MIDI instruments and parts) – first evaluation of rates
9. Correction of errors on the first-rated result, and generation (MIDI export) of a reference file
10. MIDI export

The comparison tests must be made:

- By manual, human detection of errors at step 8 (MIDI import) described above.
- By automatic, software-based comparison of the results obtained at step 10 with the reference file obtained in 9.

This methodology can only be applied to those basic features which are part of the MIDI standard, and cannot be applied to features which are not part of the standard, such as dynamic markings (hairpins, staccato, tenuto...).

7.2 The OMR Quick-Test

The OMR “Quick-Test” (version 0.1) contains three pages of basic musical features including:

- time signatures
- notes
- beams
- key signatures
- clefs
- note heads
- accidentals
- articulation
- text
- bar lines
- flat beams
- sloping beams
- stave types
- dynamics

- hairpins
- rests
- slurs and ties
- triplet and tuplets
- octava lines
- pedal symbols
- pedal lines

As mentioned above, most OMR systems use notational software front-ends. Notational software tends to use domain knowledge to interpret the data e.g. the number of beats in a bar given a known time-signature. To try and eliminate as far as possible the difficulties that misreading of this kind produces, the “Quick-Test” is designed with “correct” time to occupy each bar.

The data gathered from the “Quick-Test” should result in a list of recognition problems allowing us to target features which consistently prove problematical for the software. This will then lead to a priority list of these features.

Solving these problems will lead to more accurate initial interpretation of symbols and features, and therefore to less user-intervention.

We also look forward to input from the content providers that have supplied us with images, as well as from the OMR system developers. Their comments will help in identifying areas that are important to address if OMR software is to become more commercially viable.

Further details and information are available online at the Imaging WG section at the project website:

<http://www.interactiveMUSICNETWORK.org>

The proposed Quick-Test dataset is available for download at the Imaging WG section.

7.3 Evaluation of performance based on complete music symbols and relationships reconstruction

Beside the Quick-Test, the WG is also working on an approach for the assessment of OMR system intending to take into account the “importantness” of the each musica features and planning to offer a representative measure to measure the performance of OMR system. For further details, please see “Assessing Optical Music Recognition Tools” by I. Bruno, P. Bellini and P. Nesi available online at

http://www.interactiveMUSICNETWORK.org/wg_imaging/upload/assessingopticalmusicrecognition_v1.0.doc. Three applications have been selected in order to compare the performance in the score recognition: SharpEye2 (Visiv), SmartScore (MusiTek) and O³MR (developed at the DSI – University of Florence).

The set of complete symbols and relationships are listed and described in Fig. 1. This evaluation set is not exhaustive for all genre of music score, it could be extended in order to include more aspects (structural, symbolic, etc...). The proposed list is able to describe the monophonic music score and relationships, and the most important and frequent symbols. The relevance of each category is represented by a value of weight. The weights have been collected by interviewing a group of 13 people at the second MUSICNETWORK workshop.

Definition of test set – The missing of a ground truth databases conditioned the choice of tests, to cope with this lack, seven images have been selected from the archive of collected images at the DSI. The test-cases can be found online at http://www.interactiveMUSICNETWORK.org/documenti/view_document.php?file_id=475. The chosen music scores have the following features:

- Monophonic music.
- Font variability.
- Music symbols frequently used in the classic music repertory.
- Variable density of music symbols.
- Irregular groups (triplets, etc.).
- Small note with or without accidentals (grace notes).
- Different barlines (start and end refrain, end score, single barline and double barline).

- Clef and time signature change.
- Ornaments (mordent, turn, and trill).
- Slurs: single and nested.

Result analysis - The Fig. 2 shows tables with global evaluations on the test set respectively of SmartScore, O³MR and SharpEye2, where:

- The **Total** column reports the number of collected occurrences for each category.
- The **True** column reports the percentage rate for correct symbols
- The **Add** column reports the percentage rate for added symbols
- The **Fault** column reports the percentage rate for incorrect symbols
- The **Miss** column reports the percentage rate for missed symbols

Tables show that:

- SmartScore introduces errors in notes reconstruction and adds notes. It detects tuplets, but the main tendency is to make mistakes. It has difficulty with slurs, time signature change and key signatures.
- SharpEye 2 does not introduce notes, it has some problems with tuplets. In the grace notes detection, it does not discriminate appoggiatura from acciaccatura, it considers only grace notes as appoggiatura.
- The main limits for O³MR are due to the recognition of slurs, tuplets, grace notes and ornaments symbols. It introduces wrong slurs due to a incorrect decomposition of symbols, whereas it adds less symbols than SmartScore. It obtained the best score in Time Signature, Key Signature and Clef recognition.

The recognition of notes and rests is the most important requirement that an OMR system has to respect. They are considered the most important music symbols, and their recognition has to be robust and to provide a high performance. Tables show the O³MR capability in recognising notes and rests. In particular, the recognition rate for rests is the highest, with a difference of 13.54% with SharpEye2 and 56.77% with SmartScore. Rests, added by O³MR (4.69%), are due to segmentation errors. This is a limit for the actual version of the O³MR system.

The graphics reported in Fig.3 shows a global evaluation associated with each example. They represent respectively:

| Categories | Weight | Aim |
|---|--------|---|
| <i>Note with pitch and duration</i> | 10 | Evaluate the note reconstruction correctness in terms of pitch and duration. |
| <i>Rests</i> | 10 | Evaluate the recognition of rests. |
| <i>Note with accidentals</i> | 7 | Evaluate the association of accidentals (sharp, flat, double sharp, natural, double flat) with a note. |
| <i>Groups of beamed notes</i> | 10 | Evaluate the capability in reconstructing beamed notes |
| <i>Time signature and time change</i> | 10 | Evaluate the capability in identifying and reconstructing the time indication by recognised numbers involved in the fraction. |
| <i>Key signature and key signature change</i> | 10 | Evaluate the capability in identifying and reconstructing the key signature (tonality). The tonality is linked to the number of accidentals used in representing the key signature. |
| <i>Symbols below or above notes</i> | 5 | Evaluate the capability in identifying and linking ornaments symbols and accents (staccato, accent, turn, mordent, trill, tenuto, etc...). |
| <i>Grace notes</i> | 5 | Evaluate the capability in recognising grace notes: acciaccatura and appoggiatura are related to a single symbol while multiple grace notes define a group of notes. The multiple notes are considered a unique symbol. |
| <i>Slurs and bends</i> | 7 | Evaluate the reconstruction of horizontal symbols: slurs (and ties) and bends. |
| <i>Augmentation dots</i> | 10 | Evaluate the augmentation dots linking to notes. |
| <i>Clefs</i> | 10 | Evaluate the recognition of clefs and clef changes. |
| <i>Irregular notes groups</i> | 10 | Evaluate the capability in recognising tuplets. |
| <i>Number of measures</i> | 10 | Evaluate the capability in recognising the bar line and the number of measures. |
| <i>Number of staves</i> | 10 | Evaluate the capability in recognising staves. |

Fig. 1 - List of complete symbols and relationship considered in the performance evaluation.

- The Weighted Percentage Reconstruction Rate: it takes into account weights associated with each music symbol and relationship.

- (ii) The Percentage Reconstruction Rate: in this case music symbols and relationships have the same relevance.
- (iii) The Percentage Reconstruction Error: it considers missed, added and fault symbols. For this reason it represents a measure of the work has to be done to correct the reconstructed score.

This evaluation shows that SharpEye provides in general the best performance, whereas the O³MR is comparable with SmartScore. The O³MR obtained the best score with the example 5 (93.35%).

| Complete Music symbols & Relationships | Total | SmartScore | | | | SharpEye2 | | | | O ³ MR | | | |
|---|-------|------------|-------|---------|--------|-----------|-------|---------|--------|-------------------|-------|---------|--------|
| | | % True | % Add | % Fault | % Miss | % True | % Add | % Fault | % Miss | % True | % Add | % Fault | % Miss |
| Notes' shape with right pitch & duration | 1923 | 95.68 | 2.44 | 2.29 | 2.03 | 96.67 | 0.26 | 1.20 | 2.13 | 97.97 | 0.68 | 1.46 | 0.57 |
| Note with right associated accidental | 171 | 88.89 | 5.26 | 2.34 | 8.77 | 95.32 | 0.00 | 0.58 | 4.09 | 80.12 | 2.34 | 2.92 | 16.96 |
| Groups of Notes (Number) | 446 | 98.65 | 0.22 | 0.22 | 1.12 | 96.64 | 0.00 | 0.22 | 3.14 | 98.21 | 0.00 | 0.90 | 0.90 |
| Rests | 192 | 38.54 | 8.85 | 0.00 | 61.46 | 81.77 | 0.00 | 2.60 | 15.63 | 95.31 | 5.73 | 0.00 | 4.69 |
| Time Signature and Time Change | 41 | 31.71 | 2.44 | 14.63 | 53.66 | 63.41 | 4.88 | 4.88 | 31.71 | 68.29 | 0.00 | 2.44 | 29.27 |
| Key Signature | 74 | 32.43 | 0.00 | 35.14 | 32.43 | 90.54 | 10.81 | 9.46 | 0.00 | 93.24 | 0.00 | 6.76 | 0.00 |
| Markers | 117 | 33.33 | 13.68 | 0.00 | 66.67 | 70.09 | 0.85 | 0.00 | 29.91 | 37.61 | 1.71 | 0.00 | 62.39 |
| Grace note | 31 | 0.00 | 0.00 | 0.00 | 100.00 | 12.90 | 0.00 | 67.74 | 19.35 | 0.00 | 0.00 | 0.00 | 100.00 |
| Slur, Tie and Bend | 440 | 61.82 | 9.32 | 9.77 | 28.41 | 82.05 | 0.00 | 8.18 | 9.77 | 60.23 | 3.86 | 19.77 | 20.00 |
| Augmentation Dots | 123 | 89.43 | 66.67 | 0.00 | 10.57 | 91.06 | 11.38 | 0.00 | 8.94 | 80.49 | 2.44 | 0.00 | 19.51 |
| Clefs and Clef change | 145 | 75.17 | 5.52 | 0.00 | 24.83 | 66.21 | 3.45 | 18.62 | 15.17 | 96.55 | 1.38 | 0.69 | 2.76 |
| Tuplets | 87 | 34.48 | 26.44 | 0.00 | 65.52 | 33.33 | 1.15 | 9.20 | 57.47 | 0.00 | 0.00 | 0.00 | 100.00 |
| Number of measures | 275 | 100.00 | 2.18 | 0.00 | 0.00 | 99.27 | 1.45 | 0.00 | 0.73 | 99.64 | 1.45 | 0.00 | 0.36 |
| Number of Staves | 74 | 100.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0.00 | 0.00 | 0.00 |

Fig. 2 - Evaluation tables: SmartScore, SharpEye2 and O³MR.

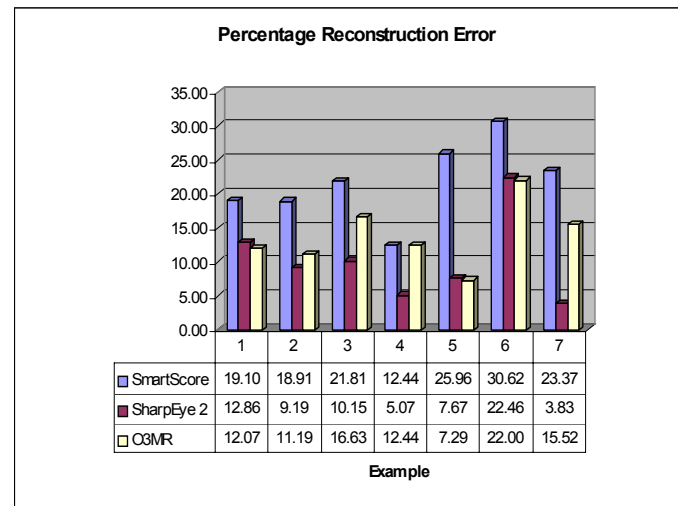
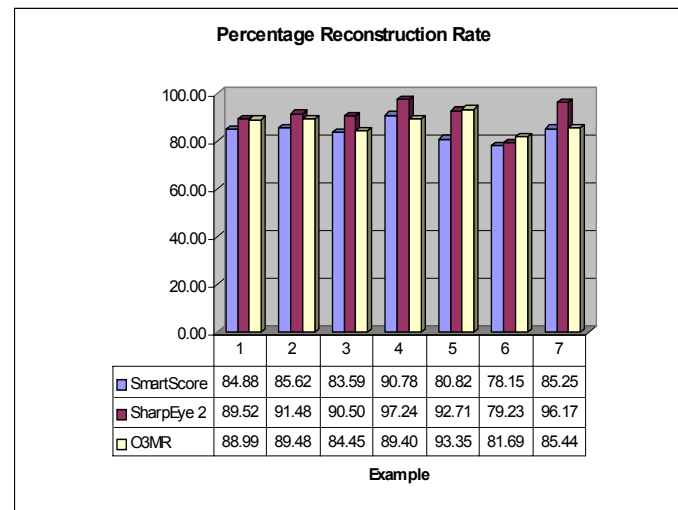
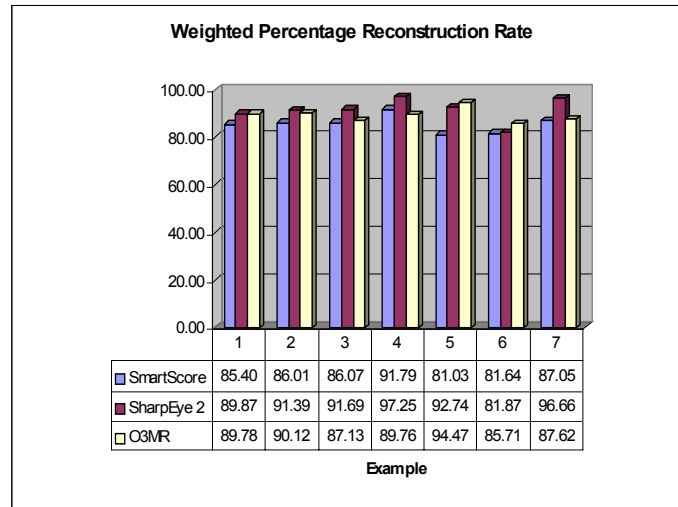


Fig. 3 – Evaluation of complete music symbols and relationships reconstruction: graphics of performance.

8 Music Image Restoration

Besides recognition and translation into machine-readable symbolic representation, graphical representation of music scores and manuscripts can also be useful for various applications, including digital preservation and cross-media integration. The idea is to digitise, extract and encode the music graphically to preserve the look and feel of the original image from the paper-based input.

This is particularly important for handwritten music manuscripts, since this approach preserves the writing style and enables scalable reconstruction and visualisation. Suitable vector graphics formats include:

- SVG (Scalable Vector Graphics); which is an XML-based 2D vector graphics file format,
- MPEG 4 BIFS,
- Postscript
- Adobe PDF
- Flash
- and others

SVG (for Scalable Vector Graphics) is a standard (a recommendation) of the World Wide Web Consortium. SVG is a language for describing two-dimensional graphics and graphical applications in XML.

Postscript is a language for description of a printed page. Developed by Adobe in 1985, it has become an industry standard for printing and imaging. The PDF (Portable Document Format) is based on Postscript, and on the ability of almost all software on major operating systems such as Windows or MacOS to generate postscript using their widely available Postscript printing device driver.

The Flash format, developed by Macromedia, is mainly based on a vector graphics format, similar in functionalities to the Freehand format of the same vendor. It is a proprietary format, even if the specifications are available.

MPEG BIFS (Binary Format for Scenes Description) makes possible to define so-called "scenes" consisting of several audiovisual objects which can be part of complex interactive multimedia scenarios. The individual objects are encoded and transmitted separately in a scene which is then composed after decoding of individual objects. Objects can be simple shapes such as circles, rectangles, text, or media such as AudioClip or MovieTexture, or even scripts.

SVG and BIFS can be considered as something equivalent: SVG is XML-based, while BIFS, even if not XML-based, owns an equivalent in the XMT format which is the XML translation of BIFS. Flash is a proprietary format, even if publicly available (with some restrictions), and is subject to evolve without notice from the owner (Macromedia). Postscript, even if being page-based, can be a good choice since translation tools are available from Postscript to SVG (Adobe Illustrator), thus to BIFS by the mean of XMT. But Postscript is not absolutely free, while the SVG standard is absolutely free of patents or royalties, like every W3C standard.

The SVG standard seems to be the best choice, for the following reasons;

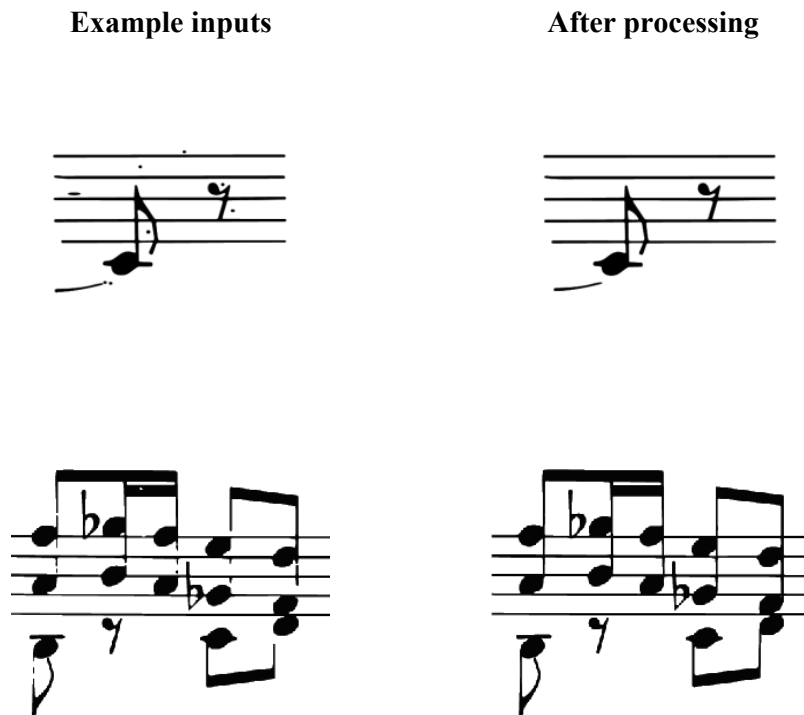
- It can generate BIFS (and even Postscript, PDF or even Flash content).
- SVG is an open standard, free of patents and royalties
- Being developed by Adobe, the format is at the level of the state of the art.

For more information about vector graphics formats, please refer to the MUSICNETWORK deliverable 4.3.1, "multimedia standards for music coding".

Typical enhancements and restorations process include reconstructing broken stave lines and stems, and removing ink spillage and noise (see Figure below). Working at this level allows minor alteration such as this. However, this is not an effective approach for modifications involving larger interconnected features or alteration affecting multiple staves.

The advantage of optical music restoration is that the processes do not jeopardise the original layout of the scores, which have been optimised by the engravers, and normally represents the ideal visual configurations. Since the original spacing of the music is untouched, there is no large modification and hence it does not

require extensive proof reading. However, the process is only concerned with small and local modifications. Larger adjustments, for example insertions or deletions of a group of symbols cannot be fully automated without altering the original layout. No full recognition is necessary for this process and hence it does not provide multimedia functionalities such as playback or search. This process is robust and it can improve the visual qualities of the scores and manuscript for reprinting and archiving.



9 Applications and Future Directions

With an effective and robust OMR system, it can provide an automated and time-saving input method to transform paper-based music scores into a machine readable representation, for a wide range of music software, in the same way as OCR is useful for text processing applications. Besides direct applications, such as playback, musical analysis, re-printing, editing and digital archiving, OMR would enable efficient translations, for example, to Braille notations [Dancing dots] or other non-western musical notations. It could provide better access and widen participation of music and at the same time introduce new functionalities and capabilities with interactive multimedia technologies and provide digital preservation of this invaluable paper-based cultural heritage.

With graphical reconstruction processes, paper-based music sheets can be digitised with the original visualisation with the capabilities of cross-media integration, extending useful functionalities for usages and applications in edutainment, long term preservation and archiving as well as widening accessibilities and participations.

Typical applications in the field of cross-media (multimedia) integration includes the following:

- Association of scores and audio performance, with automatic synchronization.
- Association of scores and video excerpts (showing details on execution)
- Association of scores and other visualisations, such as musical summaries, sonagrams...
- Hyperlinking (adding links to graphic symbols in scores)
- Convergence with audio technologies (remix, spatialisation...)
- Content-based queries, and web-based access to music (query by humming, query by example...)

- Use of the score as a reference point for studies on expressive rendering (comparison of renderings from different performers), and use of score for expressive rendering using audio synthesis software

Association of scores and musical performance can actually be made manually, but in the case of a vector-graphics based score, an automatic process can be envisaged, in the near future for monophonic audio, and in a mid-term future for polyphonic music, with the progress of automatic voice separation. Based on this All these applications have direct application in the field of education as well as in the field of music practice.

For more details on cross-media integration, see the MUSICNETWORK deliverable 4.3.1, “multimedia standards for music coding”

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