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Optical Music Recognition: Staffline Detectionand Removal

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Abstract

This paper presents the detection and removal of staff lines from the image of a music sheet. The music of composers like Mozart, Beethoven, Ravel and Chopin have mostly been preserved and digitized, the same cannot be said for the pieces composed by lesser known musicians, an Optical music recognition system provides the solution to preserving old music. In an OMR system, the first and most important step is the detection and removal of the staff lines, which are horizontal lines running across music sheets on which notes are placed. Staff lines serve as indicators of the notes' pitch and thereby help identify the note. But staff lines are a hindrance when one tries to identify the various musical symbols on a music sheet thus, the first step in most of the OMR systems is staff line detection and removal. In this paper, the removal of the staff lines will be done using two algorithms namely, Line Track Height and Adaptive Line Track Height algorithms. The performance of these algorithms will be analyzed using the parameters introduced at ICDAR (International Conference on Document Analysis and Recognition) 2011 Music Scores Competition: Staff Removal and Writer Identification. These parameters include ER or error rate, precision, recall and f.

Keywords: optical music recognition (OMR),stafflines, staffline detection, staffline removal.

1. Introduction

Optical music recognition is a computer system that can 'read' printed music [2]. Systems that can read and comprehend written word has been in existence for a few years now and; it has led to the greater availability of digitized content thus; preserving old novels and manuscripts. Music composers have been using paper as a media to translate their musical compositions into permanent masterpieces for centuries. Every region has their own distinct idea and theory on music and; an equally unique way of representing this music on paper. In Western music, the standardized notation called the Common Music Notation (CMN) is widely used to represent music. The representation of music on paper is called a music score or a music sheet. A music sheet is a very useful tool for novices and experts alike. Digitizing music sheets will not only help preserve old and antique music sheets but also help new artists compose music that can be readily printed and published. A system that aims at digitizing scores is called an Optical Music Recognition system.

OMR has been the focus of research for three decades now, but the perfect system is still far from realization. The first paper published on OMR was by scientists at MIT in the 1960s led by Pruslin. Blostein and Baird published an overview of OMR systems that were developed and researched between 1966 and 1992. Bainbridge and Bell published a generic framework for optical music recognition systems. And since then scientists have been continually conducting research into ways to improve the current Omr systems and also create a single system that is capable of doing all the functions that an ideal system should be capable of performing.

Scientists have come up with different systems over the years and; there are quite a few open source software available in addition to some expensive and professional software. OMR systems ideally should allow novices to listen to a piece of music form the music sheet for practice and also; allow musicians to translate their music directly into a music sheet[2].

There are many ways proposed by scientists on how music recognition can proceed, a majority of these methods start off with the detection and removal of staff lines. Stafflines form a large portion of the music sheet, the staff lines are simply sets of five parallel lines running through the length of the sheet. These stafflines as mentioned earlier are important in indicating the pitch of a note. They also help distinguish the key of the piece (means that the notes that the song's melody is made up of, are part of the key's scale. For example, the key of F major consists of B flat and; the notes are derived from the scale of F major- F, G, A, B^b, C, D, E.). Stafflines are a major hindrance when trying to extract individual notes and other music symbols from the music sheet. In music sheets, music notes and some of the other musical symbols have varying meanings depending on their position on the stafflines. Though the stafflines pose an obstacle in musical object extraction; they have to be detected, stored and subsequently removed from the input image in order to extract the music notes and symbols. Consequently, the stafflines are used to identify the notes and musical objects.

There are a handful of methods where OMR is performed without bothering the stafflines, as mentioned in[11]; but, most systems start the process with staff line detection and removal.

2. Music Theory

Music theory considers how aural phenomena apply in music. Musical sounds are explained by characters called notes, which are named after the first seven letters of the alphabet, namely, A, B, C, D, E, F, G. A tone is a periodic sound characterized by duration, pitch, intensity and timbre. A note in music a more complex than a musical tone. It is the sum of simple tones with harmoniously related frequencies.

The notes are written on five parallel lines called the staff lines. The names of the notes are determined by the clef which is placed at the commencement of the staff. The two clefs required for the pianoforte are the Treble Clef and the Bass Clef. Two staffs are required as a rule for the pianoforte, they are joined by a brace, as shown in Fig 1.

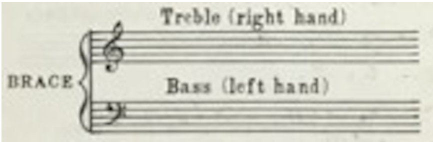


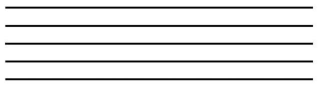
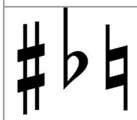
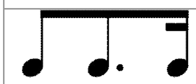
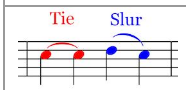
Fig 1. Stafflines and clefs in a music sheet.

A music score or sheet is used by musicians to represent music in a manner that it can be read and interpreted by other musicians in the way the composer intended. The CMN or Common Music Notation is the most widely followed notation of music in the Western world. Music from other countries are different from Western music both in the way they are interpreted and represented. In Western music, all the instruments are tuned to A440Hz, which means that the note A in the fourth octave is tuned to 440Hz.

Fig 2. A typical music sheet.

The Fig 2, shows a typical music sheet. Apart from the notes, a music sheet consists of various musical symbols that add meaning to the notes. These symbols indicate the time signature (number of beats per bar) of the piece of music, the key signature of the piece (pitch of the piece) and other grammar like whether a note is loud (forte) or soft (piano), etc. In short, a music score is a collection of notes and various other symbols represented on the staff lines. Table 1 describes some of the most commonly used music notations [11].

Table 1. Common musical symbols and their description

Symbols	Description
	Staff: Stafflines are the parallel lines running across the width of the music sheet. The notes and other musical symbols are placed on the stafflines.
	Treble, Alto and Bass clef: The notes can be identified based on the clef placed at the beginning of the piece.
	Sharp, Natural and Flat: The sharp raises the pitch of the note by a semitone, the flat lowers the pitch by a semitone. The flat brings the pitch back to its original pitch.
	Beams: Used to connect notes in note groups; they demonstrate the metrical and the rhythmic divisions.
	Staccato, Staccatissimo, Tenuto, Marcato, Accent, etc.: Symbols for special or exaggerated stress upon any beat or a portion of a beat.
	Quaver, semi-quaver, demi-semi-quaver: The note head indicates the time duration of the note while, the flag indicates the relative time of that note with respect to a closed note (1 beat note called the crochet).
	Rests: These symbols indicate a period of silence in music. There are specific rests for different kinds of notes like quarter, eighth, etc.
	Ties and slurs: Ties are used to join two same notes, which indicates that the musician should hold down the note for the duration of the tie. Slurs connect two different notes and indicate that these notes must be played in quick succession, one after the other, smoothly.
	Mordent and Turn: Ornamentsthat can change the pattern of how the notes are played.

A music score is a great tool for novice musicians to learn the nuances of music on the other hand, the ability to read a music score takes quite a while to master. With this in mind scientists came up with the idea of creating a system that can play music from a music score directly. The system also allows musicians to translate their original music into digitized music scores.

3. OMR Architecture

Optical music recognition is a system that reads and understands printed music [2]. The main objectives of an OMR system are the recognition, the representation and the storage of musical scores in a machine-readable format. An OMR program should thus be able to recognize the musical content and make the semantic analysis of each musical symbol of a music work. In the end, all the musical information should be saved in an output format that is easily readable by a computer [11].

The general OMR architecture as described by Ana Rebelo and co. is: image pre-processing, recognition of musical symbols, reconstruction of the musical information in order to build a logical description of musical notation and construction of a musical notation model to be represented as a symbolic description of the musical sheet.

The first step is image pre-processing. The pre-processing of the image can be done in many ways, such as; deskewing, removal of noise, enhancement, de-blurring and binarization. Once the image is processed the reference lengths are determined using run length encoding[11]. The staff lines are then detected using the stable path algorithm where, the entire image is treated as a graph using a weight algorithm that assigns weights depending on whether there are black pixels or white pixels [5] [12].

Once the staff lines are detected they have to be removed this is achieved in a number of ways. The most popularly used algorithms fall under four categories: line tracking, vector field, run length and skeletonization.

In Line Tracking, stafflines are first localized by some method. Each line is then tracked to see whether some of the pixels need to be removed based on some criterion [4].

In the Vector Field method pixels of the one-bit image are converted into vectors. Vector directions and lengths are used as criteria to keep or remove pixels [4].

In Runlength algorithms, black runlengths are removed based on their length or line adjacency [4].

In the process of *Skeletonization,* the bitmap image is skeletonized and this skeleton is further analyzed to obtain staff segments and symbols [4].

In this paper, two types of line tracking algorithms will be explored; line track height algorithm[3] [12]and a variant of this algorithm called adaptive line track height algorithm. After the detection and removal of staff lines the next steps include musical object recognition and conversion of that information into a MIDI (Musical Instrument Digital Interface) or MusicXML file.

4. Proposed Scheme

In this paper, the first step of optical music recognition is performed, that is; staff line detection and removal. The removal of the staff lines will be done using two algorithms and their performance will be measured and compared. The proposed system is as shown in Fig 3.

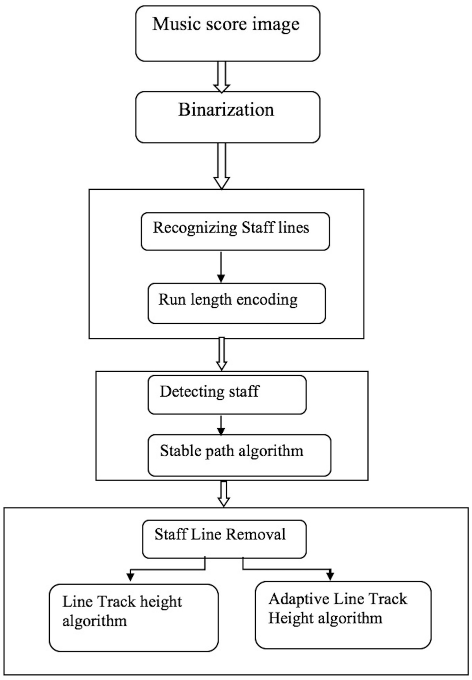


Fig 3. Block diagram of proposed scheme

4.1. Binarization

The first step in all OMR systems is binarization, it can be defined as the conversion of a grayscale image into a binary image that is composed of only two possible pixels, either true (logic '1') or false (logic '0'). This process is essential to bring to the foreground all the important components of the music sheet like the notes, clefs, slurs, ties, rests, sharps, flats, etc.

Over the years many algorithms for the binarization of music sheets were developed with the sole intention of better preparing the image for the coming steps in the OMR system. Binarization helps reduce the amount of information that the system has to compute and thereby allows one to apply better algorithms for the detection and removal of staff lines.

In general, there are two types of binarization algorithms: global and local thresholding algorithms. In global thresholding algorithms, the entire image is applied one threshold while in local thresholding neighborhoods of pixels are compared and a local threshold is computed and applied to that neighborhood.
In recent years, many content based algorithms [7] were developed that made use of prior knowledge of the image. These algorithms aimed to introduce robustness to the binarization process.
In this paper,a kind of global thresholding algorithm called Otsu's method [1] is used. The algorithm assumes that the image contains two classes of pixels following bi-modal histogram (foreground pixels and background pixels), it then calculates the optimum threshold separating the two classes so that their combined spread (intra-class variance) is minimal, or equivalently (because the sum of pairwise squared distances is constant), so that their inter-class variance is maximal. This method works well for music sheets and thus is used in many OMR systems.

4.2. Run length encoding

The next step in the process of recognizing music sheets is determining reference lengths, namely; staff line height and staff space height. This is achieved using run length encoding. Run length encoding is a compression technique but, Fujinaga and co. [11] introduced the possibility of using run length encoding to calculate the reference lengths in the music sheet. In run length encoding the number of black and white pixels in a vertical run are represented as numbers. For example, if this is a vertical run [1 1 1 1 0 0 0 1 1 1 1 0 0 0 1 1 1], it is represented as [4 3 4 3 3]. The most commonly occurring number of black pixels will represent staff line height whereas, the most frequently repeated number of white pixels gives the staff space height. Fig 4 depicts the working of Run Length encoding.

Fig 4. Run length encoding on a vertical run of pixels in the test image.

There are other ways of using this technique for example, consecutive black and white runs are summed and, the most frequently repeated number gives the sum of staff line height and staff space height [8]. Another method is by taking the sums of four consecutive black and white runs and using the most frequently repeated value as the sum of staff line height and staff space height [13].

4.3. Stable path algorithm

The detection of staff lines in the image is done using stable path algorithm [5] [12]. The image is treated as a graph the pixels form the nodes and weights are added between the pixels that act as the lines. The weights are determined using a weight algorithm, the least weight is applied for lines connecting two black pixels and the maximum weight for lines connecting two white pixels. Once the weights are added the stable paths are found, a stable path is defined as one with the least weight between the margins of the image. These stable paths are the required staff lines.

4.4. Line track height algorithm

The next step in the OMR system is the removal of the stafflines. There are many algorithms that have been introduced to take care of the removal of staff lines. One such algorithm is the line track algorithm (LTH)[3] [12]. The goal LTH is to track the staff lines positions obtained by a detection algorithm and remove vertical run sequences of black pixels that have a value lower than a specified threshold, which was experimentally set at staff line height+2. Fig 5 shows the working of the LTH algorithm.

Fig 5. LTH used to remove staff lines (marked in blue).

The idea of this algorithm come from the remark which is the vertical run of black pixel in the symbol usually significant longer than the vertical run of the black pixel in staff line. The staff line height value is computed globally from music sheet image. However, LTH does not remove staff line completely in case of staff height variation.

The LTH does quite well in most cases except for when there is a variation in the distance between the staff lines and also when the staff lines are thicker than usual. To improve the performance of the LTH the adaptive line track height algorithm was introduced[13].

4.5. Adaptive line track height algorithm

Due to the limitations of the line track height algorithm the adaptive line track height algorithm was formulated [13]. This method, as described by [13]; there are two main iterations. In the first iteration, the vertical run of black detected staff line pixel is computed. If the vertical run length value is less than a local threshold which is computed adaptively based on staff line height value of current staff line. In [13] local threshold of $2 *$ local staff line height is chosen. Local staff line height of one staff line is the mode values of all vertical run lengths value of detected staff line pixels. However, because of degradation, there are still many noise staff line after the first removal iteration. In the second iteration, tracking is done one more time to completely remove the remaining staff line pixels by connected component analysis along the staff line pixels. If number of pixels of the connected component is less than the threshold, this connected component is removed. The second iteration can remove staff line pixel noises from first iteration.

In this paper, the ALTH algorithm is there are two main iterations. In the first iteration, the line track height algorithm is used in its original form. This first iteration removes uniform stafflines.

In the second iteration, tracking is done again one more time to completely remove the remaining staff line pixels and any misclassified pixels are taken care of. The second iteration can remove staff line pixel noises from first iteration. This is done by changing the height used for comparison with the vertical run of pixels and then checking if the pixel is a staff pixel or not.

This second iteration improves the recall and reduces the error rate obtained in the first iteration. The adaptive line track height algorithm helps improve the robustness of the OMR system by ensuring that the system can handle non-uniform staff lines. Since staff lines make up a significant portion of the music sheet the accurate detection and removal of the staff lines is imperative.

4.6. Performance parameters

The International Conference on Document Analysis and Recognition (ICDAR) 2011 Music Scores Competition: Staff Removal and Writer Identification [9] set parameters to find out the robustness and efficiency of the competing algorithms namely, error rate, precision, recall and f. The competition prepared an extensive data set of images along with their ground truth images which could be used to test the algorithms and find out the parameters. This data set includes images with various distortions like curvature, rotation and white speckles in order to test various algorithms.

The performance parameters are as follows:

$$\text{Precision} = 100 * \frac{\text{no.of correctclassified sp}}{\text{no.of correctclassified sp} + \text{no.of misclassified non sp}} \tag{1}$$

$$\text{Recall} = 100 * \frac{\text{no.of correct classified sp}}{\text{no.of correct classified sp} + \text{no.of misclassified sp}} \tag{2}$$

$$\text{ER} = 100 * \frac{\text{no.of misclassified sp} + \text{no.of misclassified non sp}}{\text{no.of all sp} + \text{no.of all non sp}} \tag{3}$$

$$f = \frac{1}{\frac{0.5}{\text{Precision}} + \frac{0.5}{\text{Recall}}} \tag{4}$$

Where sp stands for staff pixels. Staff pixels are the pixels belonging to the staff lines, the pixels belonging to the symbols are taken as non-staff pixels or non sp in the formulae of the performance parameters.
Correct classified staff pixels are the number of staff pixels that have been correctly identified. Similarly, correct classified non-staff pixels are the number of non- staff pixels that have been identified correctly.
Misclassified staff pixels indicate the number of staff pixels that have been wrongly identified as non-staff pixels. The misclassified non-staff pixels are non-staff pixels that have been identified as staff pixels instead of non-staff pixels.

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Precision, eq. (1); is a parameter that shows, the accuracy with which the algorithm is able to detect staff pixels from a given input image of a music sheet. The higher the value of precision, the better that algorithm is in performing staff line detection.
Recall, eq. (2); on the other hand, is a parameter that shows how accurately the algorithm is able to remove the staff pixels without hampering the non-staff pixels of the input image. A high recall value indicates that the algorithm is capable of removing the staff lines while making sure that the non-staff pixels remain untouched.
Error rate or ER, eq. (3); is simply the overall performance of the algorithm. If it is low, it proves that the algorithm is able to correctly identify a higher percentage of staff and non- staff pixels. The ER should therefore, be as low as possible to ensure a good image of symbols and staff lines is obtained at the end of the staffline detection and removal process. This is important because, in further steps the images of the symbols and staff lines play a vital role in the identification of music notes and symbols and thereby in the identification of the music written in the music sheet on the whole.
The parameter 'f',eq. (4); like ER gives the overall performance of the algorithm. The value of f is high if the algorithm has high precision as well as recall. Its value is directly dependent on the values of both precision and recall.

5. Results

The performance of these staff line removal algorithms is tested on the images from the data set given at the ICDAR 2011 Competition. These include the image itself, the ground truth image containing the stafflines and an image containing only the symbols after the removal of the staff lines. In this paper, five images from the thickness variation set 1 from the 2011 ICDAR Competition data set are considered as inputs.

Figure 6 is the input image of the music sheet from the data set, after binarization. Figures 7 and 8 are the ground truth images of the symbols (after removal of stafflines) and the stafflines, respectively. These ground truth images are used during the calculation of the number of classified and misclassified staff pixels and non-staff pixels. These images provide the correct number of staff pixels and non-staff pixels.

Fig 6. Input music sheet image from the ICDAR data set, after binarization.

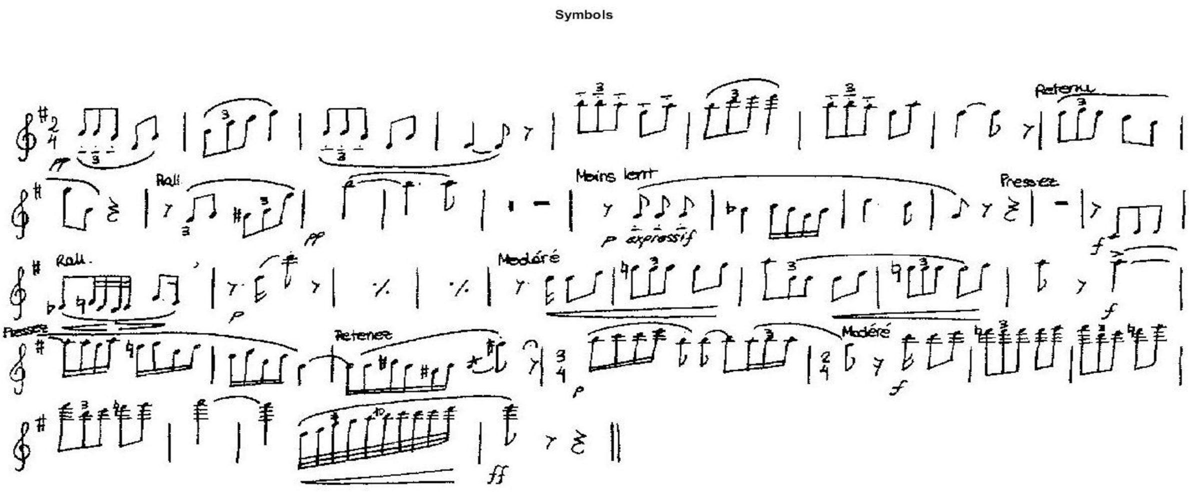

Fig 7. Ground truth image of symbols of Fig 6.

Fig 8. Ground truth image of the staff lines of Fig 6.

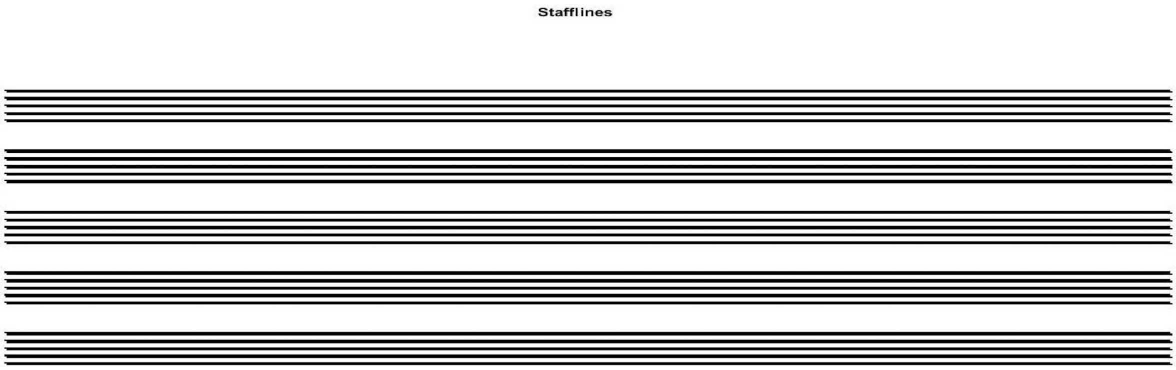

Fig 9. Detection of staff lines from Fig 6 using LTH algorithm.

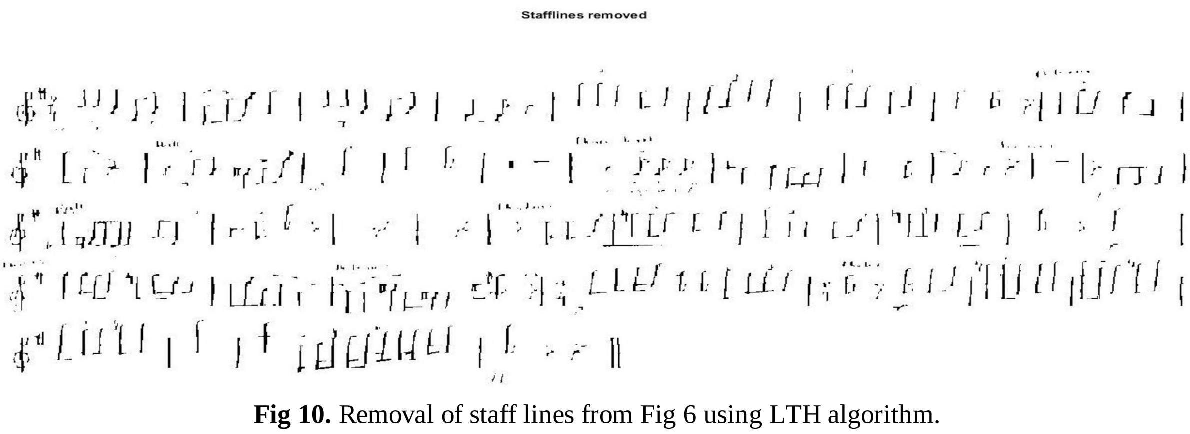

Fig 10. Removal of staff lines from Fig 6 using LTH algorithm.

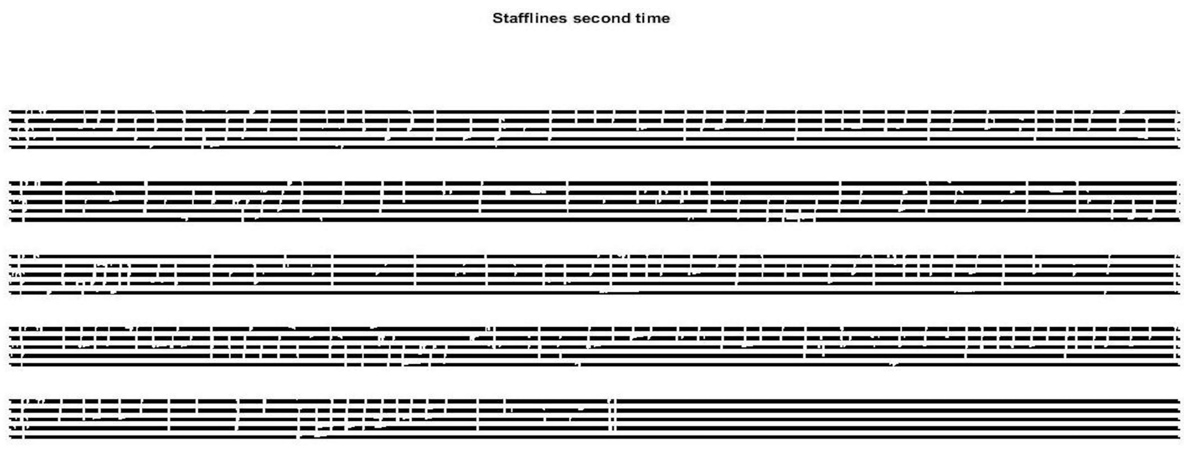

Fig 11. Detection of staff lines from Fig 6. using ALTH algorithm.

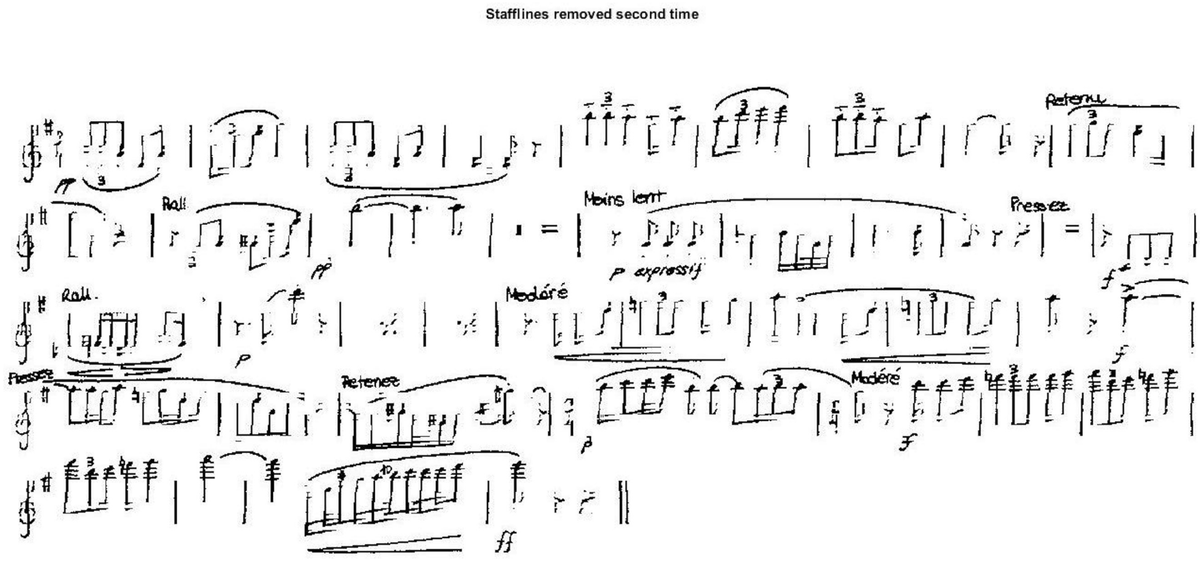

Fig 12. Removal of staff lines from Fig 6. using ALTH algorithm.

The figures 9 to 12 are the output images. Figure 9 and 10 are the outputs of the LTH algorithm while, figures 11 and 12 are the outputs of the ALTH algorithm. The LTH algorithm performs well on images of music sheets with thin staff lines. But when the staff lines are thicker than normal the LTH algorithm is unable to remove the staff pixels without removing non-staff pixels as seen in figure 10. From figure 9, it can be observed that the LTH removes the staff lines completely but as seen from figure 10; these staff lines also contain non-staff pixels from the symbols. Thus, using the LTH algorithm the a lot of non-staff pixels from the symbols are misclassified as staff pixels thus leading to decreased recall and f and; a higher ER.

The ALTH algorithm performed quite well in comparison to the LTH algorithm. This can be seen from the figures 11 and 12. The staff lines are removed more accurately without removing too many non-staff pixels. The symbols obtained from the ALTH algorithm are more clear and complete, this image will help in the identification of music notes and symbols in the later steps of optical music recognition. The number of misclassified non-staff pixels are much lesser than for LTH.

To get a clear idea of how the two algorithms performed the comparison of the parameters are compiled and put into the table below:

Table 2: Comparison of the LTH and ALTH algorithms.

	Image 1		**Image 2**		**Image 3**		**Image 4**		**Image 5**	
	LTH	ALTH	LTH	ALTH	LTH	ALTH	LTH	ALTH	LTH	ALTH
ER	10.3	6.6	7.77	4.7	8.4	4.3	8.9	5.6	7.8	4.8
Precision	97.7	97.2	98.62	98.6	98.5	98.5	98.2	98.1	98.3	98.2
Recall	89.2	93.3	92.55	95.79	92.31	96.3	90.67	94.4	92.9	96.06
f	93.3	95.48	95.4	97.17	95.3	97.3	94.3	96.2	95.5	97.16

Table 2 clearly shows the difference in performance between the two staff line removal algorithms: LTH and ALTH. As seen from the table, precision remained the same or decreased by very minute amount for ALTH. However, there was a significant increase in the recall value for ALTH over LTH, this increase in recall value resulted in a lowered value of ER and an increase in the value of the parameter f.

The four parameters' values for the two algorithms are graphically represented in the figures 13 to 16.

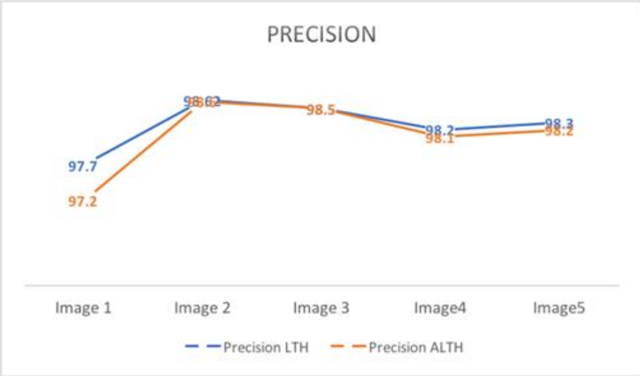

Fig 13. Graph comparing Precision of LTH and ALTH algorithms.

Fig 14. Graph comparing Recall of LTH and ALTH algorithms

Fig 15. Graph comparing ER of LTH and ALTH algorithms.

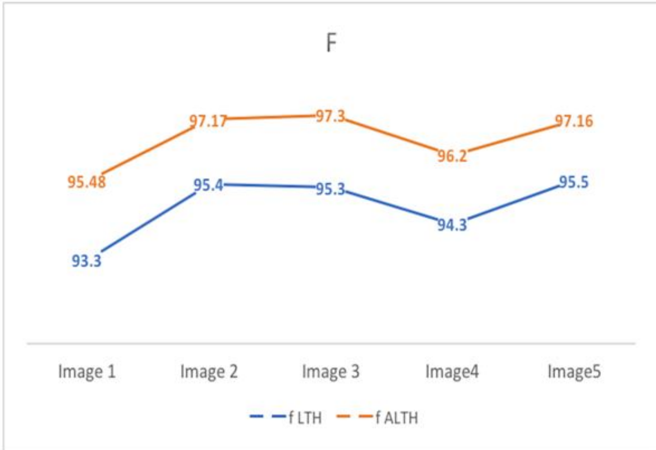

Fig 16. Graph comparing f of LTH and ALTH algorithms.

These graphs indicate the better performance of the ALTH algorithm over the LTH algorithm. As seen in figure 13, the precision of ALTH is comparable or slightly less than the value abtained using LTH. This is due to the fact that the ALTH algorithm aims at correctly identifying non-staff pixels so that the staff lines are removed without disturbing the symbols. This is essential because in the later stages of OMR symbols are treated as separate objects that have to be individually identified. Every music symbol adds meaning to the music thus, they have to be properly preserved.

In figure 14 the recall of ALTH is much higher than for LTH. The ALTH algorithm is much better than the LTH algorithm at distinguishing between staff and non-staff pixels and thus; it helps preserve the music symbols.

The error rate ER is much lower for ALTH due to the high recall value and consistent precision. The value of f is also higher because of the higher recall value.

6. Conclusions

In OMR systems since, the detection and removal of staff lines form the basic first step in majority of them, it is important that it be carried out with accuracy. In the results, it is observed that the adaptive line track height algorithm performs better than the line track height algorithm in cases where the staff lines are thicker than usual. The value of recall is improved a lot compared to LTH algorithm. The ALTH algorithm not only detected the staff pixels accurately but; it also correctly detected majority of the non-staff pixels. This characteristic of the ALTH algorithm makes it a contender for the removal of unusually thick staff lines.

Although, there is a slight dip in the value of precision the difference varies in decimal points and hence does not greatly affect the overall performance of the system. Thus, the adaptive line track height algorithm can be used for the effective removal of staff lines. The ALTH creates images of the symbols and staff lines that can serve as an accurate input for the later stages of OMR that include music object recognition and creation of the MIDI or MusicXML file.

In conclusion, the ALTH helps improve the process of optical music recognition, and thus provide novice musicians a tool to learn music and professional musicians a tool to create music with ease.

References

[1] Nobuyuki Otsu, "A Threshold Selection Method from Gray-Level Histograms", IEEE Transactions on Systems, Man, and Cybernetics, vol. SMC-9, no. 1, January, 1979.

[2] David Bainbridgeand Tim Bell, "The Challenge of Optical Music Recognition", Computers and the Humanities 35: 95–121, Kluwer Academic Publishers, 2001.

[3] Artur Capela, Ana Rebelo, Jaime S. Cardoso, Carlos Guedes, "Staff Line Detection and Removal with Stable Paths", International Conference on Signal Processing and Multimedia Applications, SIGMAP 2008.

[4] Christoph Dalitz, Michael Droettboom, Bastian Pranzas, and Ichiro Fujinaga, "A Comparative study of staff removal algorithms", IEEE TPAMI, Vol. 30, No. 5, May 2008.

[5] Jaime dos Santos Cardoso, Artur Capela, Ana Rebelo, Carlos Guedes, and Joaquim Pinto da Costa, "Staff Detection with Stable Paths" IEEE Transactions on pattern analysis and machine intelligence, vol. 31, no. 6, June 2009.

[6] A. Rebelo,G. Capela, Jaime S. Cardoso, "Optical recognition of music symbols: A comparative study", IJDAR, 2010.

[7] Telmo Pinto, Ana Rebelo, Gilson Giraldi, Jaime S. Cardoso, "Content Aware Music Score Binarization", INESC Porto, 2010.

[8] Jaime S. Cardoso, Ana Rebelo, "Robust staffline thickness and distance estimation in binary and gray-level music scores", International Conference on Pattern Recognition, 2010.

[9] Alicia Forne´s, Anjan Dutta, Albert Gordo and Josep Llado´s, "The ICDAR 2011 Music Scores Competition: Staff Removal and Writer Identification",2011.

[10] Pinto T, Rebelo A, Giraldi G, Cardoso JS, "Music score binarization based on domain knowledge", Pattern recognition and image analysis. Lecture notes in computer science, vol 6669. Springer, Heidelberg, pp 700–708, 2011.

[11] Ana Rebelo,Ichiro Fujinaga, Filipe Paszkiewicz, Andre R. S. Marcal,Carlos Guedes,Jaime S. Cardoso, "Optical music recognition: state-of-the-art and open issues", Int J Multimed Info Retr ,2012.

[12] Vítor C. Vidal, "Staffline detection and removal in the Grayscale Domain", FEUP, 26 June 2012.

[13] In Seop Na, Soo Hyung Kim, Trung Quy Nquyen, "A robust staff line height and staff line space estimation for the processing of music score recognition", Journal of Internet Computing and Services, February, 2015.