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Original article

# Expressiveness in metronomic rolls for player piano: A new field of research? ☆

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ABSTRACT

Between the last years of the nineteenth century and the first two decades of the twentieth century, the production and use of rolls for player piano became widespread. These were strips of perforated paper wrapped around a cylinder, capable of activating in the instrument a pneumatic mechanism for the automatic operation of the piano keys. The metronomic-type rolls were produced manually, by transposing the piece's score into the paper's perforation. In this contribution, we propose a solution based on the automatic identification of peaks in the distribution of the Inter-Onset-Intervals (IOIs) of the notes for the detection, within metronomic rolls, of timing-related expressive areas, i.e. of musical passages in which deviations in the length of the holes with respect to what is prescribed in the score are operated intentionally to add expressiveness. The identified algorithm, applied to a dataset of approximately 700 rolls converted into MIDI format, showed good sensitivity, and made it possible to identify in a relatively short time numerous examples of intentional expressiveness in the analyzed repertoire, commonly and erroneously considered a mere mechanical transposition of the score. In the conclusions, some reflections on the relevance of this research in the musicological field are proposed.



## 1. Introduction

During the nineteenth century, the trust and hopes placed in science fostered the development of technology applied to the most diverse fields of human knowledge. Systems for the fixation and reproduction of sound were studied. Machines capable of replicating short musical compositions multiplied, that can be summarised in the categories of the piano (or organ) with pinned barrel and those governed by perforated cardboards. Towards the end of the century, instruments capable of recording and reproducing real-world sounds were also invented: first wax cylinders and later the first forms of shellac discs.

Between the late nineteenth century and the first two decades of the twentieth century, a new technology capable of autonomously "playing" pianos became widespread, that of player pianos based on perforated paper rolls. It is not easy to accurately measure the size of the phenomenon, because in-depth studies on the extent of rolls production and diffusion are still lacking. However, it is at least possible to get a first idea of the order of its magnitude. Lawson [10] estimates as likely a total worldwide production of about 500,000 player piano rolls titles. As described in Zappalà [17], in the specific case of the Italian company First (whose total catalogue reached almost 5500 titles), in 1925 alone, the year of maximum production, about 60,000 rolls were produced. The dissemination of music through piano rolls represented a wide phenomenon, with a strong cultural and economic impact. The repertoire can be traced back in significant proportion to the context of opera, or more generally of classical music. However, there is no shortage of examples of easy-listening, traditional, dance or even ethnic music.

A player piano works based on the use of perforated sheets of paper, bearing the musical information to be converted into automatic activations of the instrument's keys and, therefore, sound [7,9,12,13]. There are two main types of player piano roll: metronomic and reproducing. The metronomic rolls were produced manually, by transposing the piece's score into the paper's perforation. The rolls called reproducing, on the other hand, fixed the actual performance of a pianist on paper [8]. Musicological research

☆ Data Availability Part of the dataset used for this study, and the software developed are available upon request to the authors.

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**Fig. 1.** A perforated cardboard, from the collection of the Department of Musicology and Cultural Heritage (University of Pavia).

has tended historically to consider essentially only the reproducing rolls, as witnesses of the performance practice of a hundred years ago, relegating the metronomic rolls to artifacts with no specific value, as they have been commonly considered simple transpositions (net of expedients for technical and sound rendering reasons) of the score.

The authors believe that metronomic rolls can also represent a valuable source of information and therefore deserve to be elevated to an object worthy of study. In this contribution, we focus on the presence of timing-related expressive passages intentionally inserted into the metronomic rolls (generally indicating with *timing* any deviation relating to the onsets of the notes).

This work is the result of a collaboration between the Department of Musicology and Cultural Heritage of the University of Pavia (Italy), which houses one of the world's leading collections of piano rolls, and the Centro di Sonologia Computazionale (CSC) [3,4] of the University of Padua, which worked on the digitization and restoration of the whole corpus of sound materials, including open-reel tapes compact-cassettes, and phonographic discs [14,15], defining an international IEEE standard (3301–2022) for the audio document preservation[1].

The following discussion is organized as follows: in Sections 1.1 and 1.2 we offer a detailed historical and technical introduction to player piano rolls and some considerations about their academic study, in Section 2 we describe the aims of this research, in Section 3 we propose an original algorithm for the automatic detection of timing related expressive areas within metronomic rolls, in Section 4 the results obtained are evaluated, in Sections 5 and 6 the results of the study are discussed, possible future developments are suggested, and the potential impact of this contribution from a musicological point of view is analyzed.

### *1.1. Historical and technical introduction to the player piano and to the rolls*

The era of the perforated piano rolls began in the last years of the nineteenth century, developed and established in the first two decades of the twentieth century, and then declined and died out (though not entirely) in the early 1930s. It is a technology that originates from the perforated cardboard technology with which small street organs, large fairground organs, or similar instruments were automatically activated in the mid-nineteenth century (Fig. 1).

The novelty of the new format of the piano rolls (in the beginning of metronomic type only) lies in the adoption no longer of heavy cardboards that unfolded like a book, with the pages pivoted one behind the other (as was the case with previous systems), but of a thinner, narrower strip of paper, fitted with smaller holes, wrapped around a cylinder. Anyway, the major difference lies in the mode of operation: while the cardboard followed a mechanical principle, whereby the holes intercepted levers that operated the strings of a piano or gave air to the pipes of an organ, the piano roll acted according to a pneumatic principle, since the holes in the paper performed only the function of switches that, letting the air pass through them, set into action small pneumatic valves that in turn operated the piano strings, avoiding direct contact of the paper roll with the mechanical part.

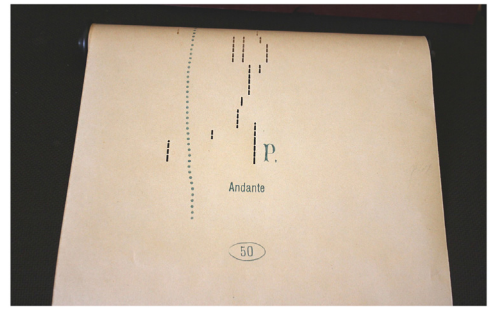


**Fig. 2.** A roll with a speed indication of 50, from the collection of the Department of Musicology and Cultural Heritage.

The player piano was equipped internally with a complex apparatus for reading the roll, that culminated externally with a special reader, a metal bar (the so-called *tracker bar*) provided with as many holes as there were keys to be activated. On the outside of the tracker bar ran the roll, while on the inside each individual hole was associated with its own pneumatic valve, which in turn was connected to the internal chamber of the instrument. When the paper roll flowed over this mechanism, as long as no perforation was present, it completely covered the tracker bar without allowing air to pass through (and thus the piano did not play); when, on the other hand, the unfolding paper on the player presented holes, the air passed through the bar, bringing into action the valves assigned to the keys, which thus resonated [16].

If we imagine the roll in its unfolding during the performance, with sliding movement from top to bottom, we will see that on the x-axis the arrangement of the holes is associated with the pitch of the sounds: holes placed on the left govern low sounds, holes placed on the right cause high sounds. The y-axis corresponds to the succession of sounds in the piece of music: the sounds follow each other as you go up along the axis. Note also that the length of the hole determines the (relative) duration of the sound: a short hole generates a proportionally short sound, a long hole a proportionally long sound. Metronomic rolls (also called standard rolls) are able to encode only two parameters of the sound, namely pitch, and duration; to manage intensity, on the other hand, there are no automatisms: for it, the performer intervenes manually at the player piano through the use of dedicated levers.

The duration encoded through the length of the hole is a relative one, since the absolute duration also depends on the speed at which the paper flows: for the same length of a hole the resulting sound will be longer if the paper flows slowly; it will instead be shorter if the paper flows quickly. The sliding speed is usually given at the beginning of the roll through a number that indicates the amount of paper (in terms of tenths of foot) that must flow in a minute (Fig. 2) and is set manually by the performer on the instrument.

From the middle of the first decade of the 20th century, the major manufacturers of mechanical instruments, in an effort to perfect the invention came to produce rolls capable of recording even the loudness assigned to each sound, an aspect that was

[1] https://standards.ieee.org/ieee/3301/11096/Last accessed March 23, 2024.

encoded in a further series of holes. This technological evolution made it possible to fix on the roll the actual performance of a real pianist, complete with all the most relevant parameters, a performance that could then be faithfully reproduced (hence the name *reproducing* to identify this type of roll). This innovation led to a clear conceptual (and also market) division between metronomic and reproducing rolls.

The metronomic rolls were worked out with a transposition that, starting from the score in conventional notation, realized the perforation of the roll by means of a mathematical-geometric calculation: each note was entitled, in addition to a precise transverse placement according to the pitch of the sound, to a perforation of a length commonly thought to be strictly proportional to its duration according to the original score. This positively resulted in a lower cost of production (there was no need to pay a pianist, and the machinery was cheaper), but negatively in the stigma of being impersonal rolls, whose music was mechanical not only in reproduction but also in its original making, being a pure and aseptic transposition of the musical text.

### *1.2. The musicological study of the rolls*

Historically, musicology has tended to take into consideration only reproducing rolls as stimulating and reliable sources on the performance practice of a hundred years ago, while relegating metronomic rolls to witnesses without documentary value, precisely because they were artificially constructed: according to this view, if there was musical expressiveness in their sonorization, it was due only to the extemporaneous action of the performer through the skillful use of the levers that managed agogic and dynamics; this action, however, took place at the moment of the performance, and there was no trace of it on the roll itself, except for generic musical indications of symbolic and verbal type (e.g. forte, accelerando, …) which, however, are not encoded in the perforation and therefore have no impact on the automatic reproduction of the roll.

But are metronomic rolls really just mere transpositions of the score? Are they really never carriers of the performance practice of the time? Is there really no trace of possible expressiveness in them?

As for indicators of the performance practice of a century ago, on closer inspection even metronomic rolls can make their own contribution worthy of attention and study. Let us give two examples. The first relates to the roll flow speed indication: it imparts to the performance an agogic progression that should testify the then perceived right speed of execution of a piece, a speed that often does not coincide with modern sensibility. The second example concerns the realization of embellishment notes: while conventional notation makes use of symbols (trills, mordents…) whose interpretation reserves a certain margin of variability, their transposition on a roll must inevitably offer only one reading, which is likely to reflect precisely the manner in which embellishments were interpreted a century ago.

As for the expressive rendering of the music contained in the rolls, it was said above that this is commonly considered to be reserved for the moment of the performance. However, part of this expressive rendering can be somewhat automated, that is, already contained in the musical encoding of the holes. In particular, since the metronomic roll cannot act on sound intensity, this can at least be done on the agogic. In other words, the one who is in charge of translating the score into the perforation of the roll can avoid assigning to the same metric value (e.g., the quaver) always the same length of the hole; instead, s/he can try to modulate that length to emulate the small or large variations in duration that a pianist usually introduces to give expressiveness to his or her performance.

## 2. Research aim

This contribution focuses on the expressiveness area of interest, described in the last part of Section 1.2. Through the development of dedicated software, we set out to test whether indeed the metronomic rolls are inexpressive transpositions of the score or whether, at least in some cases, during their production the manufacturers saw fit to introduce expressive elements already in the configuration of the holes. The possible finding of the presence of expressive passages could have adduced (as in fact it later did) an additional reason for scientific interest in metronomic rolls. The desirability of developing dedicated software was dictated by the need to reduce as much as possible the time required for the human operator to identify expressive rolls, a time that, in the presence of vast collections such as that of the Department of Musicology and Cultural Heritage, may represent an unsustainable demand.

## 3. Materials and methods

### *3.1. Dataset*

The Department of Musicology and Cultural Heritage houses a collection of more than 8400 rolls (Fig. 3). Of these, about 1400 have already been scanned and converted into Standard MIDI File 1 format, using a special scanner (Fig. 4) and dedicated software (Fig. 5), both developed by AMMI-Lab, the technological branch of AMMI (Italian Mechanical Music Association) [1].

From these, a starting dataset consisting of 107 rolls was randomly extracted from the rolls that met these criteria:

- the rolls were chosen from among those produced by the three Italian manufacturers Aurora & Apollo, First (Fabbrica Italiana Rulli Traforati) and Fratelli Cigna. The choice of these manufacturers depended on the configuration of the rolls collection, the majority of which consists of First rolls (over 55 % of the total, and the 69 % of the rolls already scanned and converted into MIDI), while among the other less represented manufacturers

**Fig. 3.** The player piano rolls room of the Department of Musicology and Cultural Heritage. A player piano is visible on the left, and on the right is the roll scanner.

**Fig. 4.** The roll scanner.

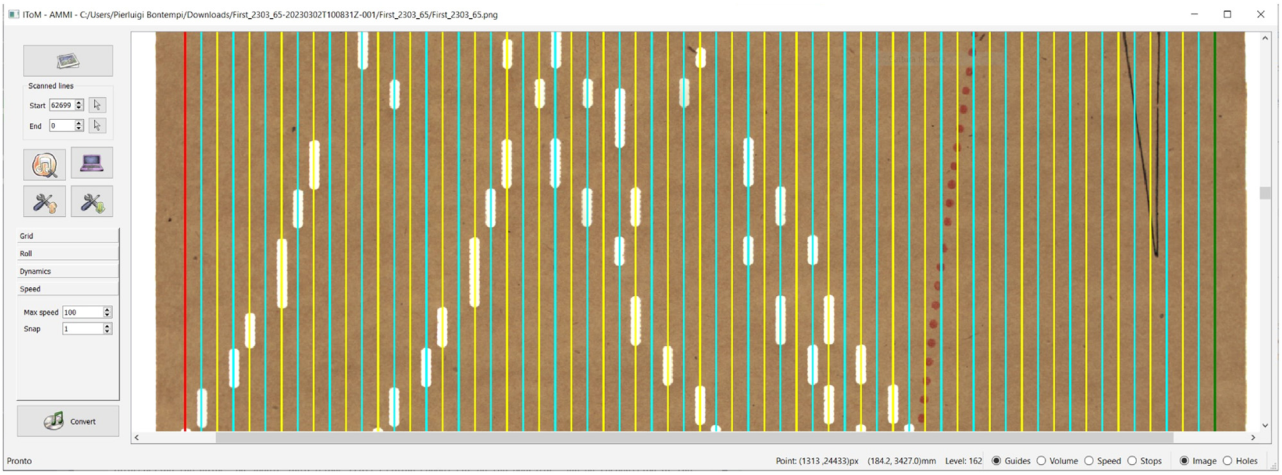


**Fig. 5.** The MIDI conversion software, showing the guides that intersect the holes.

those selected were chosen because of the availability of digitized versions and compliance with the following conditions;

- the rolls should have no obvious defects, nor should any problems have arisen during digitization and conversion to MIDI format;
- the rolls had to have a single speed indication, valid from the beginning to the end of the roll;
- during the conversion to MIDI format of the roll, the operator should not have made any manual agogic changes.

To better clarify the third item on the list above, we specify that during the course of the roll explicit changes in the flowing speed may be present, but there may also be *de facto* metronomic time variations on different sections induced by intervening only on the perforation of the paper, without explicitly stating it. For roll selection only the absence of explicit flow speed variations was taken into account.

All these MIDI files were carefully listened to by the authors, and apparently intentional expressiveness occurrences were noted, so that they could be compared with the results of the software.

After this first stage, a batch implementation of the algorithm was applied to all the rolls that met the above criteria (a total of about 700 pieces), leaving the human operator with only the task of verifying the areas considered by the software to be potentially expressive.

### 3.2. MIDI format conversion and features

The MIDI conversion software operates on the basis of guides intersecting the holes (Fig. 5), on recognition of the holes based on the different color with respect to the paper, and on dynamic and agogic (roll sliding speed) indications set by the operator.

In the generated Standard MIDI File the Set Tempo meta message and the Pulses Per Quarter Note (PPQN) values are always fixed, respectively, at 500,000 and 96. This means that the temporal resolution (the time covered by 1 MIDI tick) is just over 5 ms (500,000 ms / 96), which is more than adequate to represent the roll and reveal possible expressive deviations.

### 3.3. The algorithm for the expressive sections detection

Although, to identify agogic variations, it is possible to apply beat tracking algorithms, this approach does not necessarily represent the optimal solution, or at least the only possible one, for the area under study. There are multiple reasons for this:

- even the best beat tracking systems are prone to error [11];
- as shown in Fig. 6, in player piano rolls the beat times are subject to continuous oscillations, which may make it difficult to distinguish between intentional expressive agogic variations and unintentional oscillations attributable to the intrinsic limits and production practices of the medium;
- in music transcribed for piano rolls there is a frequent use of short notes as appoggiaturas or ornaments, which could mislead the tracking algorithm;
- beat tracking systems may not offer insights about what happens within each beat, and could therefore miss minor expressive timing deviations.

Therefore, we propose a different approach to the identification of potential expressive areas within player piano rolls, to be used alone or in conjunction with beat tracking systems or other solutions capable of improving the detection. The software with which the identified algorithm was implemented was written in Python language, with the use of the additional libraries Mido [2], NumPy, Pandas, and SciPy.

First, the MIDI file is parsed and information about the start and end times of each note is extracted. The total duration of the notes is also calculated, to exclude the shortest ones (under 5 MIDI ticks - 26 ms at 120 bpm/96 PPQN). When a note starts at a maximum distance of 10 MIDI ticks (52 ms at 120 bpm/96 PPQN) from the beginning of the next one, it is considered to be in sync with it. In this way, simultaneous notes are treated as single rhythmic events. It is also obviated the potential problem of correctly recognizing appoggiaturas or ornaments, which generally consist of short notes placed at a minimum temporal distance before the more structurally significant ones. This yields a linear sequence of relevant rhythmic events, with associated IOIs (Inter-Onset-Intervals, the time separating the onsets of two events). A dataframe containing this information is created.

Since note durations in music are encoded in proportional terms, and metronomic rolls are basically transpositions of musical scores, it is natural to expect a high number of occurrences of IOIs corresponding to the rhythmic values used in the piece (e.g. minims, crochets, quavers and so on). In a quantized MIDI file, all the IOIs associated with the same rhythmic value would correspond exactly to the same number of MIDI ticks. This is not the case when MIDI conversions of rolls are taken into consideration: rather than univocal values, for each relevant rhythm figure ranges of values that are more or less wide depending on the case have to be taken into account, due to the accuracy limitations inherent in the medium (Fig. 7). The basic idea behind our approach is that through a properly set peaks detection algorithm it is possible to

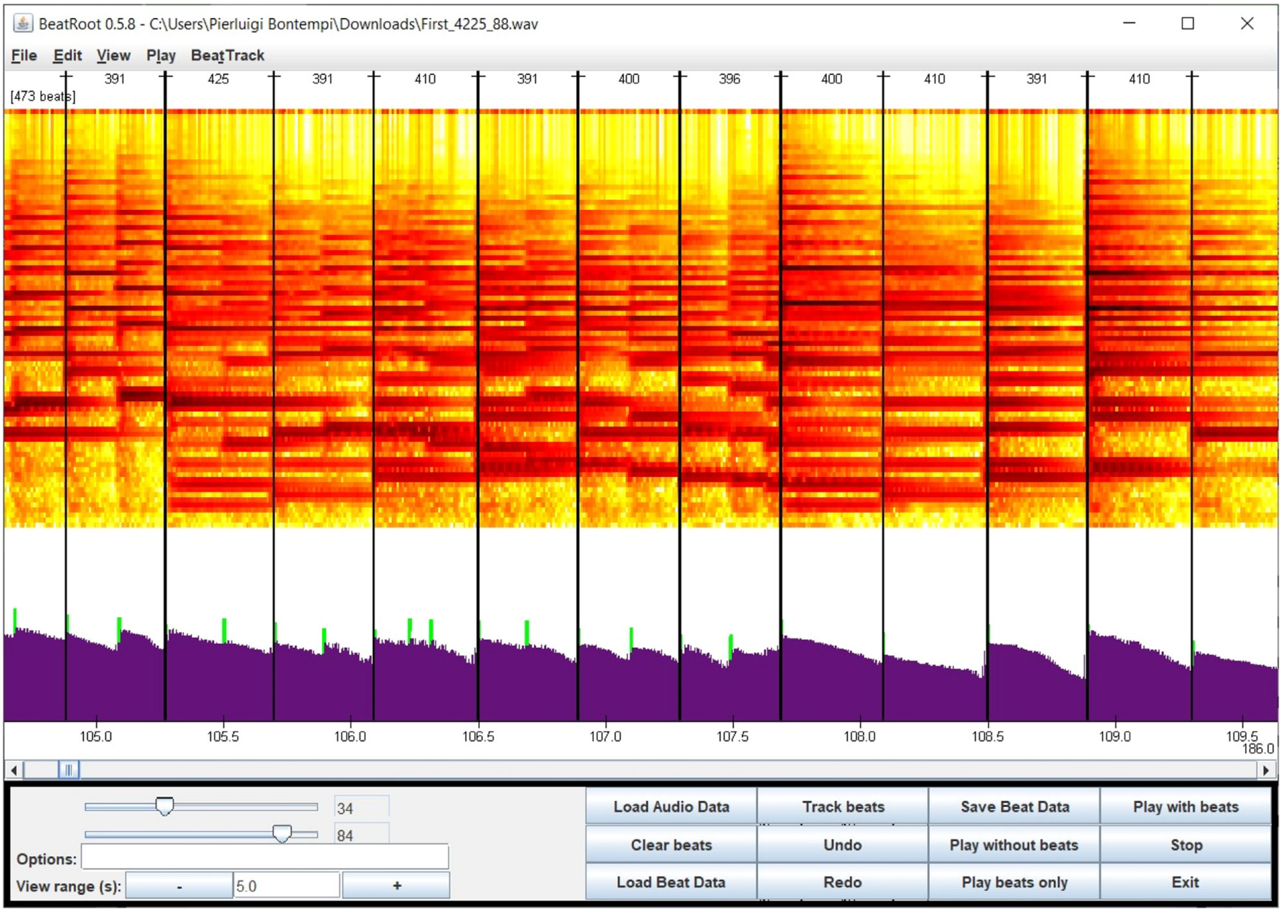


**Fig. 6.** A section of the audio rendering of the MIDI file obtained from the roll First 4225, analyzed through the beat tracking system BeatRoot, described in Dixon [5]. Just below the text menu on the top, the numbers indicate the milliseconds between each detected beat.

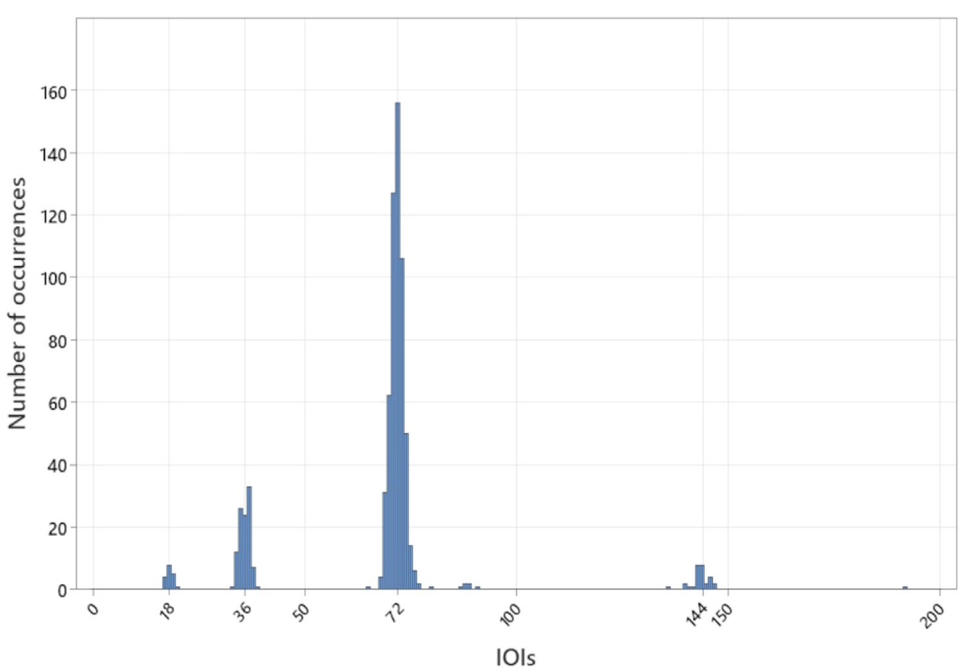


**Fig. 7.** The distribution of the IOIs (in MIDI ticks) in the roll First 0115.

identify the number of MIDI ticks corresponding to the rhythmic values used in the piece and associate to the IOIs that do not correspond to these peaks a score related to the distance from the nearest peak, representing the extent of the time deviation of the IOI from the theorically "correct" note length. Areas that exceed a predefined cumulative deviation score threshold will have high probabilities of representing expressive sections from a timing perspective (i.e., passages in which timing deviations are introduced intentionally to add expressiveness).

After obtaining an ordered array containing all IOIs, via SciPy's signal.find_peaks function the significant peaks, associated with the rhythmic values used in the song, are detected. This function requires as input a one-dimensional array and finds all local maxima comparing the neighbouring values. In addition to the array of detected IOIs, optional parameters of *height* (with a value of 10), *threshold* (with a value of *None*) and *distance* (with a value of 5) were set. This means, respectively, that at least 10 close IOIs are required to induce peak detection, no constraints are placed on the vertical distance between contiguous samples, and there must be a minimum distance of 5 MIDI ticks between peaks. The indicated parameters valorisations were derived experimentally, trying different solutions on the initial dataset of 107 rolls, until a fine-tuned setting, functional in almost all cases, was achieved.

*Virtual peaks* corresponding to twice the values in MIDI ticks detected are added, as long as they do not fall within the range between the peaks already detected. This serves to include among the reference "non-expressive" duration values those associated with the longer notes, which are less frequent in the pieces.

Each IOI is then matched with a score, calculated on the basis of the number of MIDI ticks of distance from the nearest peak. Each peak governs an area ranging from 1/2 to 3/2 of its value in MIDI ticks. Outside this area no score is computed, since the legitimacy of tracing the specific IOI to a deviation of the nearest peak would be questionable. Anyway, from the experimental data obtained it has been shown that this situation involves a residual number of IOIs.

To account for the different significance of the deviations depending on the reference peak, the scores are normalized dividing them by the ticks value of the nearest peak. For practical purposes, the score is then multiplied by 100. For example, an IOI of 200 MIDI ticks, 15 MIDI ticks away from the nearest peak of 185 MIDI ticks, generates a score given by $\text{abs}(200–185)/185 \times 100 = 8$.

Potentially expressive areas are identified based on the cumulative score for a section of the piece (that is, of a grouping of contiguous notes).

Two versions of the software were produced: the first processes one file at a time and allows the user to set score threshold and grouping size; the second is dedicated to batch processing, and does not allow you to change parameters between MIDIs. The single file version was used for the initial dataset of 107 rolls, the second for the remaining rolls.

As with the peak detection function, the optimal values of score threshold and notes grouping were defined experimentally, based on the initial dataset.

In most cases, threshold and grouping values of, respectively, 80 and 3 provide good results. In some cases, the threshold had to be lowered to better match the expressive passages, but this happened in a significant way only when the detected peaks were numerous and not well spaced. This usually happens when the roll is divided into multiple sections, each one with its specific tempo (despite the fact that this is not made explicit through indications such as the one in Fig. 2). For this reason, in the batch version of the software, rolls generating more than six peaks (excluding the *virtual* ones) were automatically excluded from the analysis.

## 4. Results

For each MIDI file, the software outputs a list of possible expressive areas. For example, the roll First 0130, with a score threshold set at 80 and grouping IOIs at 3 gives as a result:

```
First 0130
Potential expressive area from 2 min and 8.9 s to 2 min and 10.3 s
Potential expressive area from 4 min and 0.6 s to 4 min and 1.9 s
```

Given that, by listening to the MIDI file associated with this roll, the authors had noted an expressive passage starting at 4′00″, in this case the first detection is a false positive, while the second one is correct.

Usually, false positives may be due to duration values rarely used during the piece, lack of precision in the perforation of the roll, or threshold and grouping parameters not adequate to the specific roll.

In the initial 107 rolls, the authors judged upon listening that 16 contained expressive passages, and 91 contained no significant ones. Of these 91, the software in 48 cases correctly detected the absence of expressive passages, in the others it generated at least one false positive. Out of a total of 40 expressive passages detected on listening, 34 were detected correctly by the software, in 19 cases with score threshold at 80 and grouping at 3, in 15 by lowering the threshold value.

Then, using the batch version of the software on the remaining dataset with threshold set at 80 and grouping at 3, it was possible to identify, in a relatively short time, 24 more expressive passages, spread over 17 rolls. Lowering the score threshold value would increase the sensibility, probably detecting more expressive areas, but also increasing false positives.

The use of the software described could be useful in speeding up the work of listening to MIDI files by excluding those that most likely do not contain expressive areas. It might also be useful to quickly identify a good portion of the expressive passages, but these should be validated by listening to distinguish them from false positives.

To handle rolls containing multiple sections with different tempos, it would be useful to integrate the software with a beat detection system, so that the roll is automatically divided into homogeneous sections.

## 5. Discussion

From this initial experimentation, it seems that a not insignificant number of metronomic rolls includes agogic expressiveness directly in the configuration of the holes, although it is still unclear according to what criterion the same roll manufacturer sometimes undertook to prepare rolls with these expressive nuances, while at other times limited itself to a completely impersonal, purely mathematical transposition of the score.

It seems obvious that it is important to identify expressive rolls, because they can contribute significantly to the study of performance practice.

A noticeable improvement in the accuracy of the detections could be achieved by supplementing the proposed system with beat tracking algorithms or with information about the musical structure of the piece (most of the expressive passages detected within this first dataset can be traced back to the insertion of rallentandos at the end of musical sections). Another possible approach, suggested in Dixon and Cambouropoulos [6] (in that case used to improve a beat tracking algorithm), consists in taking into account the musical salience of the notes, evaluated on the basis of dynamics, intonation, and duration.

It is our intention to integrate our solution with other approaches to improve the reliability of the detections.

## 6. Conclusion

This work has shown how metronomic rolls cannot always be considered mere mechanical transposition of the musical score. Quite the contrary, they can be carriers of valuable information about early twentieth-century performance practice.

In addition to piano rolls, the same technology could be used to investigate perforated cardboards and pinned barrels, provided they are scanned and converted into MIDI format.

At the same time, the road taken with the present contribution could open up new fields of investigation, linked for example to the evaluation of the precision in the realization of the rolls, or to the analysis of the characteristics of the length of the holes according to the manufacturer, period of production and repertoire.

We hope, therefore, that in the future academy will be able to devote itself to this object of research, which has hitherto received little attention.

## CRediT authorship contribution statement

**P. Bontempi:** Conceptualization, Methodology, Software, Visualization, Validation, Writing – original draft, Writing – review & editing. **P. Zappalà:** Resources, Supervision, Validation, Writing – original draft, Writing – review & editing. **S. Canazza:** Conceptualization, Methodology, Supervision, Validation, Writing – review & editing.

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## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.culher.2024.04.004.

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