AUTOMATIC PITCH RECOGNITION IN PRINTED SQUARE-NOTE NOTATION

Gabriel Vigliensoni
gabriel@music.mcgill.ca

John Ashley Burgoyne
ashley@music.mcgill.ca

Andrew Hankinson
andrew.hankinson@mail.mcgill.ca

Ichiro Fujinaga
ich@music.mcgill.ca

Aim

We developed a fully searchable, web-based version of the *Liber Usualis*, a well-known service book that uses *square-note notation* and contains most of the texts and chants for the offices and masses of the Roman Catholic church.

This project presents our research in the development of an automatic system to recognise the pitches of all neumes across the 2000 pages of the book.

Workflow

Pre-processing

The pre-processing step separates the page elements (frames and borders, title, ornate letters, in-staff music symbols, lyrics, inter-staff text elements, and titles) into different layers, as can be seen in Fig. 1. The separation of the elements was performed using the automatic page layout analysis system of *Aruspix*, an application devoted to OMR on music printed during the European Renaissance. We manually corrected any misclassified page elements.

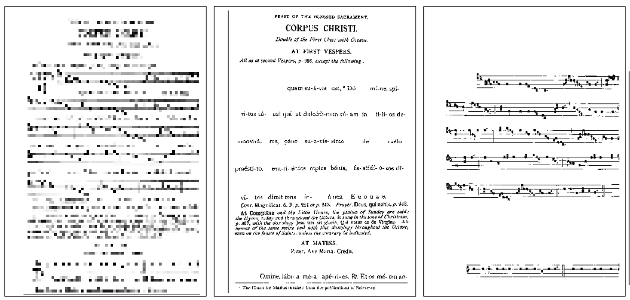


Figure 1. Page pre-processing: (a) original image, (b) only text content, (c) only musical content

Staff detection and removal

We processed the images containing only music notation with the *MusicStaves Gamera Toolkit*. This toolkit allowed us to extract each staff line position and store its location for later determination of pitches, as can be seen in Fig. 2. We also remove all lines for later glyph classification.

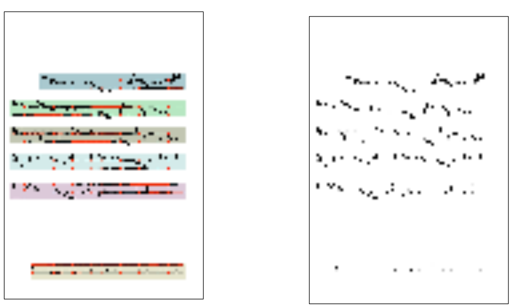
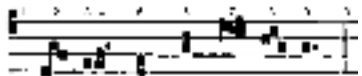


Figure 2. (a) Staff detection, and (b) staff removal

For the staff detection we tested two different staff-finding algorithms. For the first approach , we retrieved the average vertical position of each one of the lines across the whole page and named this approach *avglines*. The second approach used the Miyao algorithm, which breaks a staff line into equidistant segments, to provide a more precise means of determining horizontal staff slope changes. We named this approach *miyao*.

Neume classification and labeling

The glyphs from 40 pages of the *Liber Usualis* were manually classified to create a training dataset for automatic classification using the *Gamera interactive classifier*. In addition, we developed an encoding scheme to capture the shape of the entire neume, its intervals and other auxiliary elements attached to it. This encoding scheme also served as a class identifier, as can be eseen in Fig. 3.



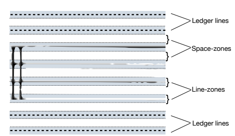
Glyph	Labeling	Glyph	Labeling
1	clef.c	6	neume.podatus.2
2	neume.torculus.4.2	7	neume.porrectus.2.2
3	neume.punctum	8	neume.torculus.2.3
4	neume.podatus.2.dot	9	neume.punctum.dot
5	neume.cephalicus.2	10	division.major

Figure 3. Encoding scheme example

Pitch recognition

Zones and ledger lines

To calculate the pitch of the starting point for each neume, we created imaginary lines, ledger lines, and zones, line- and space-zones. in the staff and calculated the placement of neumes in these zones.



Horizontal projection and centre-of-mass

To find the starting pitch for each neume we created a sub-image with a width of the size of a single punctum. We then retrieved the horizontal projection of each sub-image and calculated its centre-of-mass. By using this method, we found the mean location of the starting position of a neume, and we determined its zone in the staff, allowing us to derive its starting pitch.

As the clef modifies the pitch of each note, the coordinates where each neume was located was stored temporarily, and its pitch was assigned according to the clef.

Special neumes and neume modifiers

Neume shapes such as *podatus*, *epiphonus*, *cephalicus*, *scandicus* and their variations required further processing because their sub-image shape have two vertically stacked notes or elements, shifting the centre-of-mass. We split them horizontally, and the centre-of-mass of the sub-image's largest connected component was then considered the centre-of-mass of the neume.

Neumes with modifiers, such as *vertical* and *horizontal episemas*, or *dots*, were also treated specially by removing these elements before calculating their vertical position in the staff.

Moving the space- and line-zones

The position of the space- and line-zones had an impact in the performance. We tried two approaches: a *regular spacing*, with all zones equidistantly distributed, and a *shifted spacing*, with the upper line of the space-zone shifted down by 2/16 of the staff-space in that staff-segment, and 1/16 for the lower one.

Testing and Results

We tested our system using six different variants based on the *avglines* and *miyao* staff-line detection, the treatment of some neumes with special conditions (*exceptions*), and a *regular* or *shifted* zone spacing.

nomenclature	staffline detection	exceptions	zone spacing	legend
MES	miyao	yes	shifted	
MNS	miyao	no	shifted	
AER	avglines	yes	regular	
ANR	avglines	no	regular	
MER	miyao	yes	regular	
MNR	miyao	no	regular	

As can be seen in Fig. 4, the *cephalicus* and *podatus*, and to a lesser degree the *epiphonus*, *scandicus*, and *torculus* share a common pattern: their best results were achieved with the variants that include handling of the special exceptions. and so it is clear that these special exceptions were necessary. On the other hand *clivis*, *porrectus*, and *punctums* have in common that their best recognition was accomplished using MES and MNS, i.e., the variants that include both *miyao* and a *shifted spacing*.

Overall, the best variant performance was achieved by MES, with a 97% recognition rate in finding the pitch of the first note of a neume.

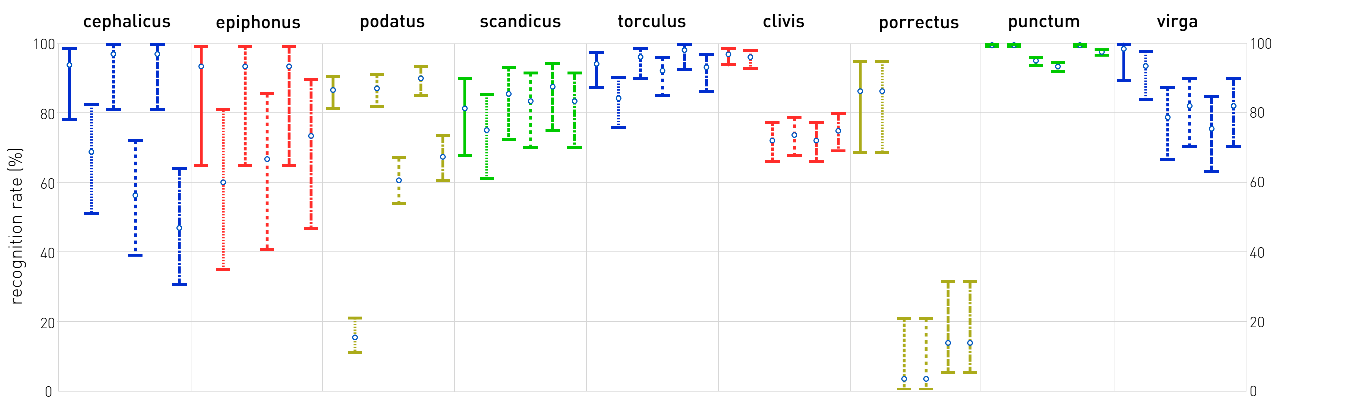


Figure 4. Precision and error bars in the recognition rate for the neume classes in our ground truth dataset for the six variants of our pitch recognition system

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