The concept of using information technologies for the study of sacred monody's structure

Based on the 1674 Lyubachiv irmologion

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Abstract
The use of the capabilities of computer technologies has long been used for the classication, systematization, and analysis of musical texts based on the material of folklore and vocal-instrumental genres. However, such research was not conducted on musical samples of medieval sacred monody, although this material allows us to establish the formative intonation patterns of European music. The study of the selected repertoire of the Lyubachiv irmologion of 1674 with the help of digital tools is a means of building intonation and lexical dictionaries of Ukrainian culture of the 17th century.

Keywords
Sacred monody, MusicXML, AntConc, monody structure analysis, music structure analysis

1. Introduction

Ukrainian art is vividly represented in the liturgical plane, in particular in the medieval monody – unison liturgical singing. This is an iconic singing repertoire, preserved in handwritten notated collections of the 16th-18th centuries – irmologions, which, in addition to being purely liturgical, also served as a singing textbook for all Ukrainian children. Therefore, the number of irmologions grew rapidly, and the musical motifs and poetic vocabulary of the repertoire were quickly mastered. In the future, this significantly influenced the content and form of numerous literary, artistic, and musical genres of Ukrainian culture.

For research, we chose the Lyubachiv irmologion of 1674, created by Pavlo Smerechanskyi [1]. It is kept in Lviv in the Historical Museum (RUK 103), its repertoire is one of the most complete, and the text is written in a small semi-script with elements of cursive, very clear

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and easy to read. The collection is decorated with skillful ornamental screens, initials, and decorations on the margins. All this, along with calligraphic writing, distinguishes the Lyubachiv irmologion of 1674 as a particularly elegant and, at the same time, capacious collection.

Attempts to combine music and mathematics or computer analysis approaches are not new [2], [3]. Applying information technologies not only to preservation but also to the analysis of the musical texts of the Lyubachiv irmologion is an actual task [4], it is complex and involves specialists from various areas, such as musicians, musicologists, computer scientists, data and knowledge analysts.

2. Study of monody: bibliometric analysis

The bibliometric analysis consists of a quantitative evaluation of the publication activity on the subject, followed by the qualitative analysis of the publications [5]. The main research questions (RQ) of the bibliometric analysis on the subject of monody structure study will be: 1. What is the number of relevant papers devoted to the monody analysis over the last 10 years? 2. What are the main subject areas of the papers on the monody analysis? 3. Authors from what countries contributed to the monody research the most?

The Scopus indexing database was chosen as the source of trustworthy, peer-reviewed works. The “monody” was used as a search word, and searched within Article title, Abstract, Keywords sections (all results are true on May, 31st, 2024). As a result, 169 papers were found. As the next step, the papers from russian federation and in russian were excluded. Of 153 papers remaining, 69 papers from the 2014-2024 period were analyzed. Of them 14 were excluded, as they were not connected to music or monody. Fig. 1 shows the dynamics of the publication activity since 2014 (RQ1), and presents the geographical distribution of papers being published on the monody study (RQ3).

Among 56 analyzed papers, 69.3% had Arts and Humanities as a subject area, 26.7% were of Social Sciences, 2.7% were of Computer Science, and 1.3% of Psychology (RQ2). As mentioned, the Computer Science subject area was 2.7% of the papers, which is two papers. In 2017 Italian scientists adapted a linguistic technic of stylometry to attribute medieval liturgical monody with a quantitative approach [6]. In 2023, the deep neural network was presented to classify Persian music genres [7].

It is obvious, that information technologies are not widely used for monody analysis, which can be explained by the lack of interdisciplinary cooperation between musicians, musicologists, and IT specialists. The current work aims to fill in the gap of interdisciplinary approaches between music and information technologies and uses the Ukrainian monody as the research object (Figure 1).

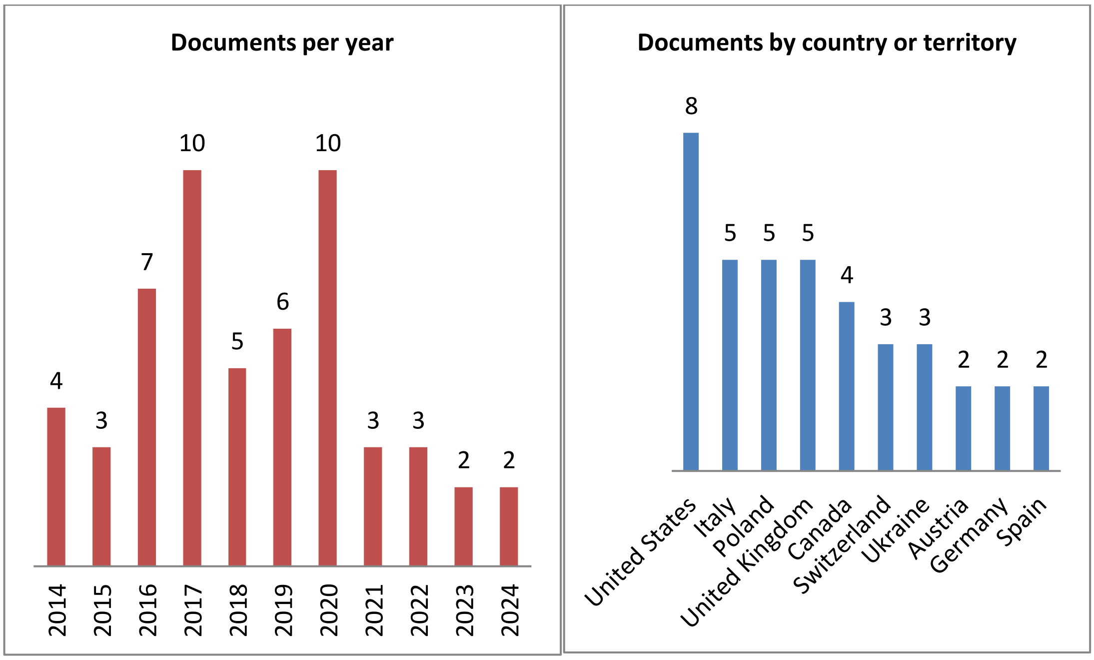


Figure 1: Quantitative analysis of the open access papers on monody study.

3. Information technologies in IT support of monody structure analysis

Let us consider the steps of the algorithm of monody structure study with the use of information technologies, and as the object of research, we will use the Lyubachiv irmologion, namely, the eight songs of the first Mode. We shall indicate the functionality or type of the corresponding information technology in Table 1. The input data for initiating the process of studying the monody structure is a digital music sheet with a score in linear notation. Such music sheets can be in the form of a digital photo of a book page (Figure 2a), in the form of an editable music score, typed with a score writer [1], [8] (Figure 2b), or in non-editable form (in PDF, see Figure 3).

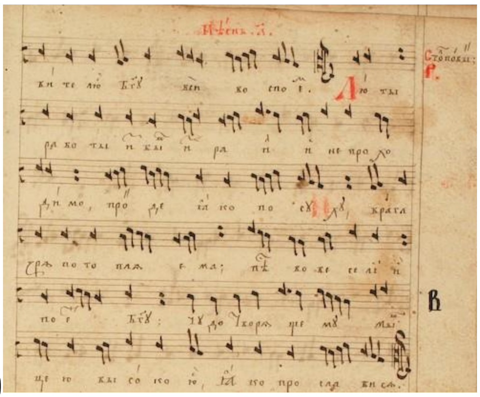
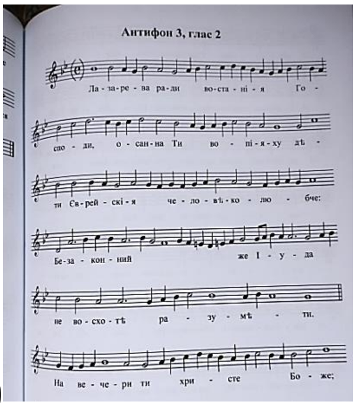
a) 

b) 

Figure 2: The digital photos of Lyubachiv irmologion`s first mode: (a) from the 1674 book, and b) from the [1]).

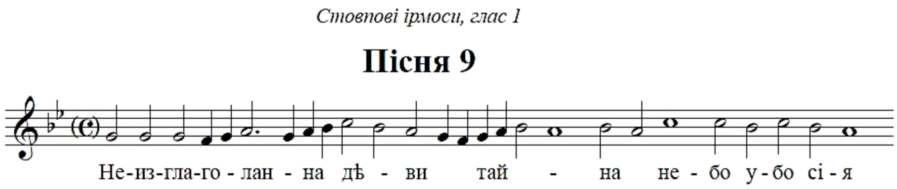



Figure 3: Music sheet with Irmose`s Mode 1, Ode 9 [8] in linear notation.

Table 1
Algorithm of information technology support of the monody structure study

Step No	Step description	Relevant IT	Comments
0.	Receive input data – digital music score	PC, smartphone, photo camera, scanner	
1.	If the music score is editable, go to Step 5, otherwise go to Step 2.	Score editing software	Online/desktop software, paid.
2.	If the music score can be recognized, go to Step 4, otherwise go to Step 3.	Music optical character recognition (OCR) software	Desktop software, mostly paid, or with limited time of free access.
3.	Create the music score, go to Step 5	Score writing software	Online/desktop software, paid.
4.	Recognize the music score	Music OCR software	Desktop software, mostly paid, or with limited time of free access.
5.	Convert music score into machine-readable format	Score editing/writing software	Mostly paid, online/desktop version
6.	Perform quantitative analysis	Data analysis software.	For data analysis, designing new software might be expensive. On the other hand, it might be extremely difficult to find existing data analysis software with specific functions, to be re-purposed to the music score analysis.
7.	Perform qualitative analysis. End of the algorithm	PC, text editor, etc.	Generally accessible, free

According to the algorithm from Table 1, if the input information is the PDF file of a music score in a linear notation, as in Fig. 3, the algorithm`s steps sequence will be the following: Step 0 -> Step 1 -> Step 2 -> Step 4 -> Step 5 -> Step 6 -> Step 7, and information technologies to be applied are the PC, score editing/writing software, data analysis software, text editor. For the input data as in Figure 2(b) (provided by the author, Natalya Syrotynska), in Step 4 the Capella-scan software [9] was used for the Music Optical Character Recognition process [10].

With such procedure, eight odes of the first mode of Lyubachiv Irmologion`s Irmoses were recognized and then converted into machine readable formal of MusicXML [11]. Figure 4 presents the first note of the score from Figure 3 in MusicXML format.

```
<note>
        <pitch>
                <step>B</step>
                <octave>4</octave>
        </pitch>
        <duration>960</duration>
        <voice>1</voice>
        <type>half</type>
</note>
```

Figure 4: Note in MusicXML format.

4. Peculiarities of displaying monody musical texts in the MusicXML format

In the MusicXML format, the description of each note depends on its complexity. The elements <note>…</note>, <pitch>…</pitch>, <step>…</step>, <octave>…</octave>, <duration>… were used to describe most of the notes of the studied monody in MuscXML. </duration>, <voice>…</voice>, <type>…</type>. Its explanation and short statistics on the converted into machine-readable MusicXML format odes are in Table 2.

Table 2
Description of MusicXML format elements for odes of the first mode of the Lyubachiv irmologion. The statistics of the first mode of the Lyubachiv irmologion

Marking	Description	Occurrence in MusicXML format of the first mode of the Lyubachiv irmologion (times)
<note>…</note>	Start and end note description	(626)
<pitch>…</pitch>	Height (of the tone)	(626)
<step>…</step>	Letter notation	A (179), B (118), C (74), D (27), E (17), F (62), G (149)
<octave>…</octave>	Octave	4 (541), 5 (85)
<duration>…</duration>	Duration	480 (342), 720 (1), 960 (216), 1920 (51), 1440 (16)
<voice>…</voice>	Voice	1 (626)
<type>…</type>	Type	Quarter (342), quarter_dot (1), half (216), whole (51), half_dot (16)

According to such statistics, an assumption can be made. Being abstract, chant`s music score can be considered as a text, and each note can be treated as a word, as in linear notation it is surrounded by spaces. We do agree with [6] and [12] that some linguistics approaches can be applied in musicology. And implementation of the text analysis software can lead to some acceptable results in intonational architectonics research.

Following such an assumption, the AntConc software [13] was chosen to consider its application to monody structure analysis. If the decision on the possibility of linguistic analysis software application in music score analysis is drawn positive, it will mean that AntConc is the re-purposed software, mentioned in Step 6 of Table 1.

5. The AntConc text analysis software for the monody`s structure analysis

The AntConc is a free text analysis software, which was used in various research, such as [14]. As input data, it needs .txt or .doc document format, and words separated with space. Every non-letter is considered a separate character, which makes it impossible to work directly with the music score in MusicXML format. So, the data preprocessing should be performed.

From Table 2 analysis, all the notes have the voice equal to 1, so we can omit this information. The note duration and type are equivalent (960=Half), and the numerical value can be omitted. Octave is only 4 or 5, so we shall code it with Four or Five, respectively. Following these simplifications, we will code every note MusicXML format into single-line form, for example, the note from Fig. 4 will be coded into BFourHalf.

After notes of all odes of the Irmose`s first mode were coded, the files were saved in .docx format and then uploaded to AntConc software. Figure 5 shows the File View tab of the AntConc, with eight odes uploaded, and Ode Nine`s content is mapped.

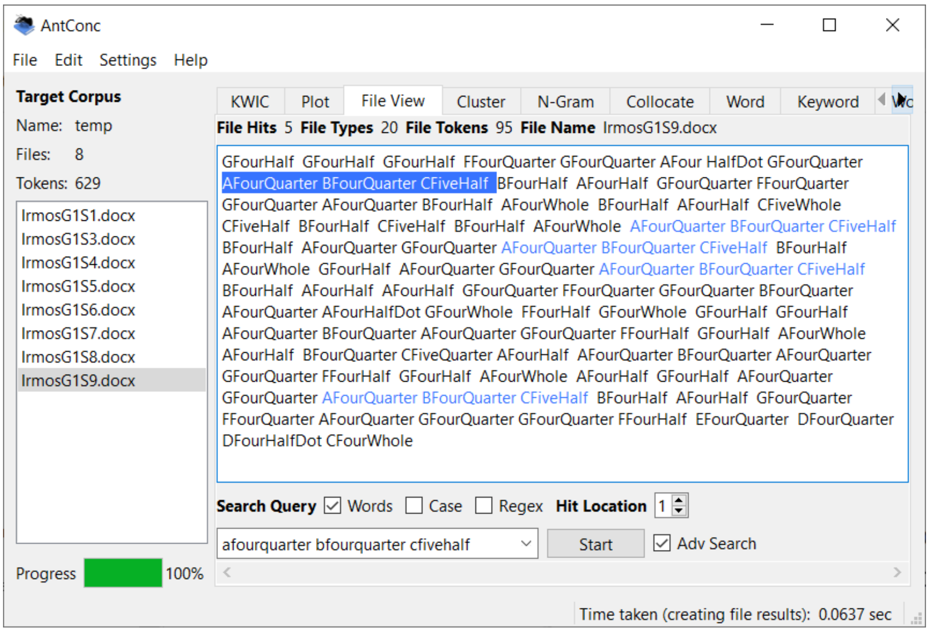


Figure 5: The FileView tab of AntConc software.

It can be seen, that the Ode 9 has 95 tokens which are notes, and 20 different notes are in this Ode.

Opposite to the language, the single note analysis will not be informative, and AntConc has a tool to analyze the sets of words (notes here). The N-grams tab allows analysis of n-grams, the chain of n notes, that occur more frequently than once. For justification regarding the length of the alalysed chain, we will turn to O. Tsalay-Yakymenko [15]. Analyzing the structure of the Ukrainian monody, the researcher took three notes as the basis of the structure of the musical formula. So, in the AntConc settings, on the N-Grams tab set the value of N-Grams Size to 3. After pressing the Start button, we will receive the results of the frequency analysis of trigrams (Figure 6).

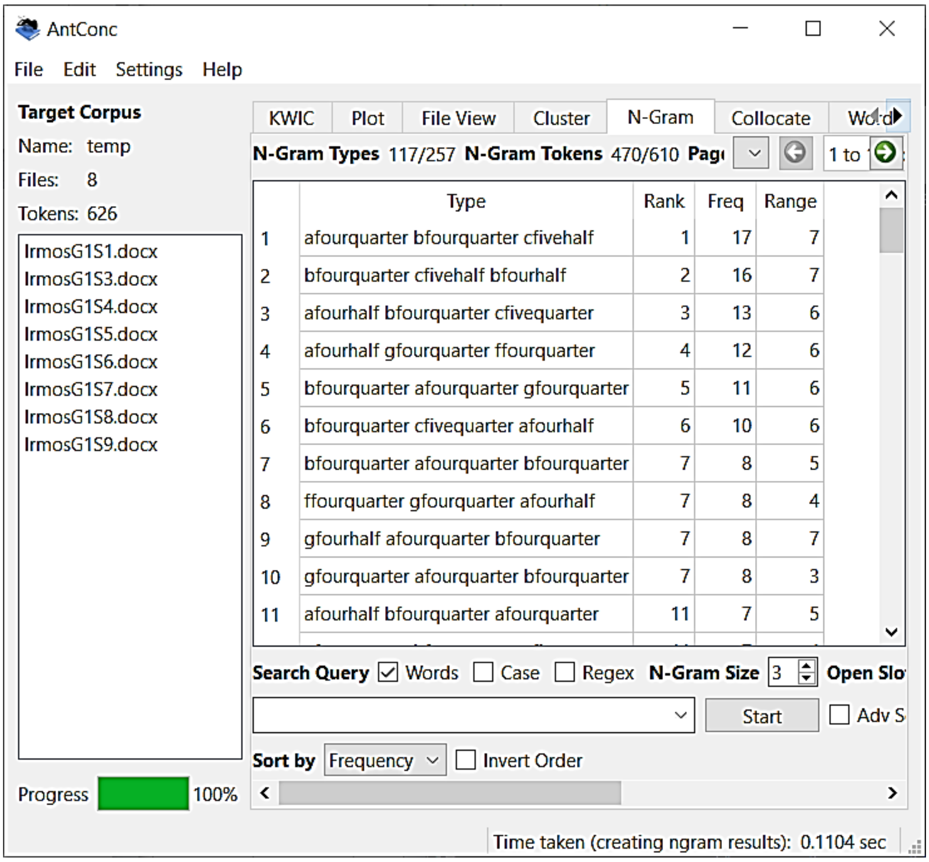


Figure 6: The N-grams tab in AntConc (N=3).

The calculated results indicate that the most frequent trigram is

AFourQuarter BFourQuarter CFiveHalf,

in linear notation, see Figure 7.

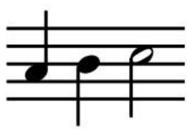



Figure 7: The most common trigram of the first Mode.

Among the AntConc functions there are no relevant tools to analyze the structure of the monody, namely, are there any organization or arrangements of musical elements in an ode.

To perform such analysis, the NoteFinder software was designed. Functional demands for such software were the following:

- Files in MusicXML format as input data.
- Analysis of multiple files.
- Allows uploading music sequences to search for.
- Allows searching for different music sequences simultaneously.
- Allows visual representation of the search results.
- Saving both visual and quantitative information.

Such software was developed in python Jupyter Notebook (.ipynb) format but was packaged as .exe program, which means for software to work correctly, the archive should be unpacked, and .exe file should be run.

The NoteFinder software has no dependencies on the operating system. Minimum hardware requirements:

- Processor: AMD Athlon X2 2.8 GHZ, Intel Core 2 Duo 2.4 GHZ.
- Ram: 2 GB.
- Video card: DirectX 10.1 (AMD Radeon HD 6450, Nvidia GeForce GT 460).
- DirectX: version 11.
- Network: No internet connection is required, software runs locally.

As sequences to analyze, we used top-10 frequent trigrams, as it was found using AntConc software (see Figure 8). Found sequences were created in MusicXML format.

Users can upload numerous music sequences, and then choose which of them to analyze, if not all. In Figure 9 the main window of the designed software is presented, with a list of files uploaded (to the left).

The results of the analysis present the number of musical structures (called constellation) occurrences in each Ode. Each constellation is marked with a different color, as mentioned in a legend on top of the window. The charts represent the organization of the constellation in a music score of the Ode. Fig. 10 presents a closer view of Ode 3, Ode 5, and Ode 6 structure by NoteFinder. From the visual analysis, it is seen, that three of Odes have a rather similar beginning.

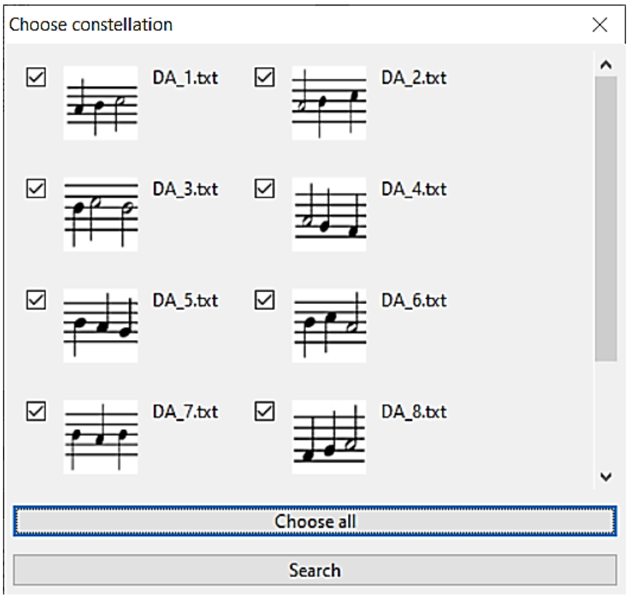


Figure 8: Note sequences to analyze in NoteFinder.

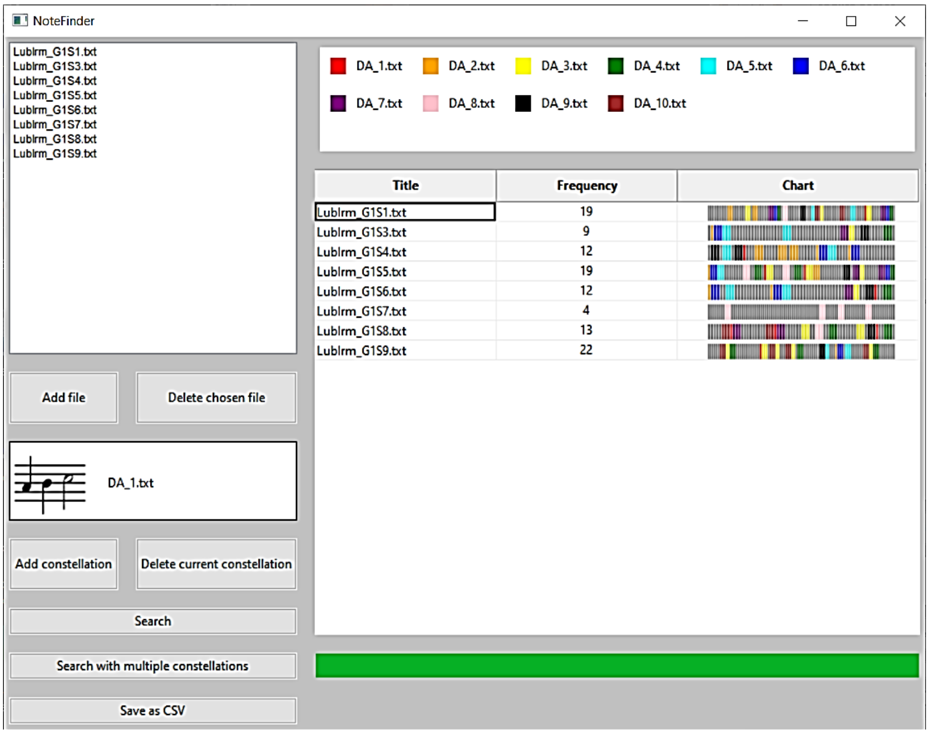


Figure 9: The NoteFinder software window with results of analysis of the eight Odes of the first Mode.

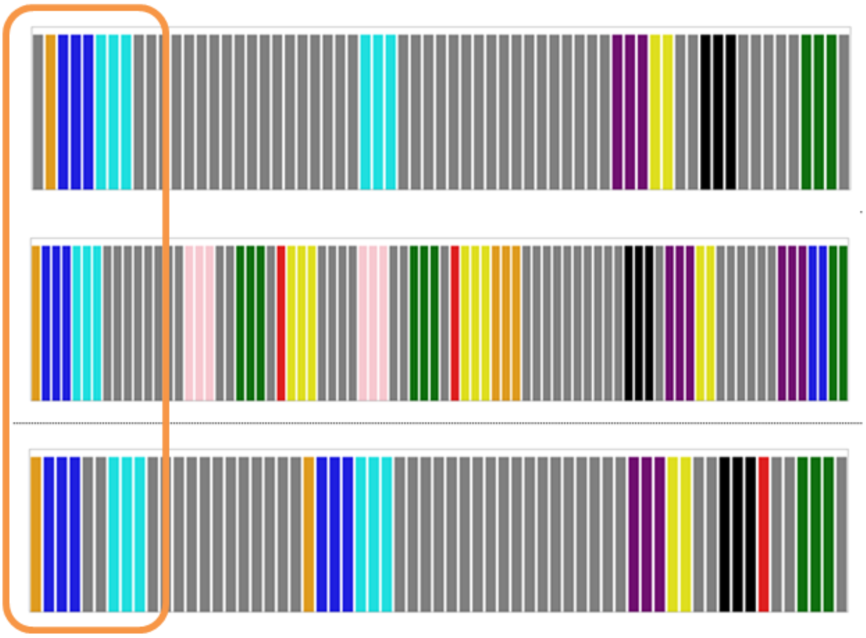


Figure 10: Constellations of Odes 3, 5, and 6.

From Figure 9 it is seen that Ode 7 has the least number of the constellation in it, and this is the only constellation. These results can be also retrieved from the .csv file, which NoteFinder exports (see Figure 11).

Songs Name	DA_1.txt	DA_2.txt	DA_3.txt	DA_4.txt	DA_5.txt	DA_6.txt	DA_7.txt	DA_8.txt	DA_9.txt	DA_10.txt
LubIrm_G1S1.txt	2	2	3	2	2	2	2	1	1	2
LubIrm_G1S3.txt	1	1	1	1	2	1	1	0	1	0
LubIrm_G1S4.txt	1	5	0	0	2	2	0	0	2	0
LubIrm_G1S5.txt	3	2	3	3	1	2	2	2	1	0
LubIrm_G1S6.txt	2	2	1	1	2	2	1	0	1	0
LubIrm_G1S7.txt	0	0	0	0	0	0	0	4	0	0
LubIrm_G1S8.txt	3	0	2	2	0	0	2	1	1	2
LubIrm_G1S9.txt	5	1	5	3	2	1	0	0	1	4

Figure 11: Detailed quantitative results of the constellations occurrence in Odes.

Combining visual and numeral results, it is seen, that the most various Odes are 1st, 5th, and 9th, and they have the most numerous appearances of constellations. It can be commented as the first, middle and the last Ode are as if they are framing the Mode.

6. Conclusions

This paper presents an algorithm for IT support of a process of monody structure analysis. Such analysis involves knowledge of information technologies and musicology, which makes such research interdisciplinary. While studying the monody with adapted software (AntConc) and software specifically designed for such analysis (NoteFinder), it is too early to draw any conclusions on the monody's structure, as only one Mode was analyzed, which is a limitation to such research. Nevertheless, this paper presents a viable approach, the continuation of such research depends on the volume of the analyzed material. To overcome the mentioned limitation, authors are working on widening the music scores in machine-readable format to be analyzed with the NoteFinder software. The current task is the creation of an electronic mapping of one of the Ukrainian monody's artifacts, the Lyubachiv irmologion, to be accessed freely, in various digital formats:

- Book`s pages as the pictures, in image file format.
- Odes as a sequence of pictures, as an image archive.
- Odes in score-edited format.
- Odes in interchangeable, machine-readable format (MIDI, MusicXML).
- Odes texts in text editable format.

Being able to analyze and draw reasonable, quantitatively proved conclusions, the monody researchers will add to deepening the sphere of values and ideas about the essence of Ukrainian identity, to the preservation of medieval national artistic heritage, and to expand educational programs of various specialties, including practical and performing artistic directions. Also, the formation of a lexical dictionary of the 17th century is the prospect of further linguistic research.

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