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# The technology of notation of musical notes

Stanislav Bolanča[1, 2], Ivana Bolanča Mirković[1, 2,] Dubravko Banić [1]

¹University of Zagreb Faculty of Graphic Arts, Getaldićeva ulica 2, Zagreb, Croatia
²Croatian Academy of Engineering, Kačićeva ulica 28, 10000, Zagreb, Croatia

Correspondence: khajdek@unin.hr

## ABSTRACT:

The evolution of music notation is closely tied to the broader societal and technological advancements of civilisation. With the entry into the industrial age, certain printing techniques emerged as the most efficient methods for reproducing musical notation. In addition to technical prerequisites, the standardisation of musical notation plays an important role, in enabling consistency in the transmission of musical information. A significant turning point marks the end of the 20th century – the integration of computer technology into the process of notating music. This opens up space for the development of specialized software tools intended for notation and graphic representation of musical works. It is expected that future development in this area will be marked by the increasing integration of computer systems with devices for graphic reproduction, which further improves the precision, speed and accessibility of musical notation.

This paper presents a review of relevant professional and scientific literature to present the historical development of methods of notating music, technological milestones in the process of its reproduction, and modern computer solutions that shape the future of musical notation. The results of the review indicate that technological innovations, especially digitalization and the development of computer tools, are key factors in the transformation of the way music is written.

## KEYWORDS:

Standardization of musical notation, Musical notation, Graphic reproduction of the original

## 1. INTRODUCTION

Sounds, or music, have always attracted people. The change of generations created a need to transfer knowledge about music from older to younger ones. There are two motives: memorization and communication. The condition for exact transmission was, in addition to the text, to write down the pitch, their duration and loudness. By writing down, and notating, music can be protected for a long time. [1, 2]

## 1.1. Writing music

Evidence of the existence of a musical civilization is the invention of a wind musical instrument in Mesopotamia. It was made of bone, and dates from around 5000 BC, and artistic depictions of musicians and music appear around 4000 BC. Pictograms for the "harp" appear from that era. [3] According to some sources, the oldest song was written around 3500 BC in what is now Syria, while others believe that the complete text of the hymn was written by the

Sumerians before 3400 BC. [4, 5] The text is written in cuneiform. Harps and lyres were already present in Ur before 2600 BC. Later, Egypt adopted the harp and the square drum. [6, 7]

Author Roberto Finka believes that the seven tones diatonic scale and the harmony concept existed in Sumerian music before 3400 BC. Significantly, musical notation has existed in Egypt since around 3000 BC. [5, 7] Some eastern peoples also tried to write down music. Namely, at that time music was passed down from generation to generation by oral tradition. In Egypt, musical performances most often took place in temples. Musical culture has a stable development over time and is counted from 2700 BC. At that time, musical instruments and choral rhythmic beating existed. Music was often accompanied by dancing. The length of the recording and the rhythm could not yet be recorded. [8] These musical parameters were usually left to improvisation. Author Roberto Finka believes that the diatonic scale of 7 tones and the concept of harmony existed in Sumerian music before 3400 BC. [9]

It is very significant that in Egypt from about 3000 BC there were musical notations. [10] Some eastern peoples also tried to write down music. Namely, at that time music was passed down from generation to generation by oral tradition. In Egypt, musical performances most often took place in temples (Figure 1). Musical culture has a stable development over time and is counted from 2700 BC. At that time, there were musical instruments and choral rhythms. Music was often accompanied by dancing. [11, 12] The length of the notation and the rhythm could not yet be recorded. [13] These musical parameters were generally left to improvisation.



a)



b)

Figure 1 a*) Painted scene of a musical ritual in Egypt [15], b) Mesopotamia detail of the "Peace Scene" of the Standard of Ur [14],*

The oldest recorded poem is Hurrian Hymn No. 6 from the ancient Ugaritic civilization (present-day Syria), written in cuneiform around 1400 BC (Figure 2). The notation includes clef marks that indicate musical intervals, rather than individual notes like modern notes. The system uses string names and numerical instructions (e.g., "3rd string, press 5th fret"), suggesting a specific playing technique. [16] The song was most likely played on a 9-string lyre, a similar instrument used throughout Mesopotamia. The intervals are written with numbers that correspond to the ratios of the strings – a similar principle later used by Pythagoras. The text of the song is partially preserved. Although not yet fully deciphered, it is thought to be religious, probably a prayer or hymn to the goddess Nikkal.



Figure 2 *The oldest written song [17]*

Music in Egypt is associated with science, and music initially had 5 points created on an astronomical basis. The addition of 2 tones creates a scale with 7 symbols corresponding to the planets' symbols. [18] The movements of the hands of the leading performer

determined the movement of the melody. Some songs have been found written on ceramics, and some have been preserved on papyrus.

Music was also important in ancient Greece. Thus, the scientist Pythagoras (571 – 497 BC), who was also involved in music, noticed that the strings of musical instruments produce tones in harmony when the coefficients of the lengths of these strings are whole numbers. [19] The concept of the "music of the spheres" (Musica Universalis) was first introduced by Pythagoras and later expanded upon by thinkers such as Plato and Kepler. This idea suggests that the universe operates according to harmonious mathematical principles similar to music. [20]

The oldest musically developed and deciphered musical notations originate from ancient Greece. Depending on various sources, they appear as early as the end of the 6th century, in the 7th century BC, or 250 years BC. e. [21] These are systems where, for example, for each instrument, it is written which string should be pressed on which field. There, the strings and pitch are indicated by letters. Special symbols indicate the duration of the tone. [22]

One of the important notations is a fragment of musical notation from the Temple of Apollo, part of the so-called Delphic Hymn to Apollo (Hymn 1 and 2 to Apollo) (Figure 3). The notation dates from around 128 BC and is written in vocal Greek notation.

All Greek records of that early time are preserved only in fragments, and the oldest preserved complete record is found on a tombstone. Seikilus' Skoliion and Seikilus' Epitaph are the oldest fully preserved compositions in the world, created around 200 BC. The text of the song and the musical notation in ancient Greek notation are carved into a pillar that is a tombstone. [24] Systems for recording music are also developing significantly in China, Japan and India. The melody is often written next to or over the text, but the rhythm is very freely read and performed. [25] During the Roman Empire, the legacy of music notation from the Greek era was largely neglected, so Greek inscriptions from the first centuries of the new era were only later deciphered with the help of documents from other found writings by Roman music theorists. [26]

The neglect of existing ways of notating music went so far that in 625 the Bishop of Seville declared that music could not be written down. However, Pope Gregory (590–604) propagated church singing. The legacy of this is the Gregorian chants. [27, 28, 29] Some authors believe that the earliest deciphered musical notations are from the author Aurelian around 850. Similar, more or less similar notations are found in various European countries. The problem of the height of individual musical notations is solved by introducing horizontal musical lines into the musical notation itself. First, only one horizontal line is introduced. [30]
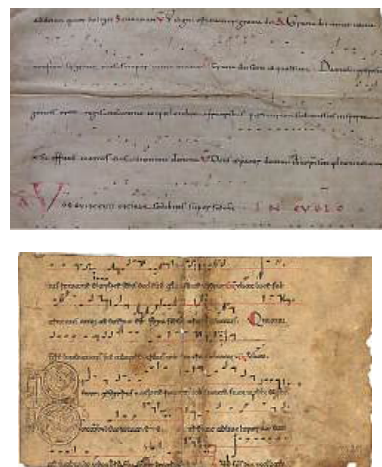


Figure 3 *Fragments of Athenaeus's Paean [23]*



Figure 4 *Musical notation with one horizontal line: a) Limoges,[31] b) Montecassino manuscript [32]*

Figure 4 a) is a typical example of the "one-line staff" from Limoges, which is often described in studies of early Neum notation. Figure 4 b) shows the Montecassino manuscript from the 11th century. The mentioned example is typical of the Beneventan tradition with one line, most often depicted in red or yellow. The line indicates a fixed height and serves as a reference base for height relationships between neumes.

Later, notes were written in a system with two, and then with four horizontal lines. The author of such a system is considered to be Guy de Arezza (991–1050). This created a musical notation, and it was most often used for the needs of monasteries and churches. [32, 33] There were also notations in different colours, which further expanded the possibilities. [34]

The Epitaph of Seikilus is considered the oldest surviving complete musical composition with notation. The epitaph was found in Tralles (present-day Aydın, Turkey) and dates to the 1st or 2nd century AD. [35]



Figure 5 *Page of a composition written in a system with four horizontal lines[36]*

The development of writing music on four horizontal lines is traditionally attributed to Guido d'Arezzo (c. 991–1050), a medieval Benedictine monk and music theorist [37]. He introduced a four-line system (quadriline system) to more precisely indicate the pitch of notes, which was a significant step in the development of modern musical notation (Figure 5). Guido d'Arezzo is considered the author of an early system of solmization, in which he indicated the

notes with the letters ut, re, mi, fa, sol and la. [38] He presented this system in his treatise. In his early 11th-century Micrologus, he expounds the principles of musical teaching and notation.

Later, the syllables ut were replaced by do, and ti (or si) was added to complete the solmization system with 7 notes (do, re, mi, fa, sol, la, ti).

Perotin made a further major advance at the end of the 11th and beginning of the 12th centuries. He wrote notes in a line with 5 horizontal lines.[39] The result is a way of notating the pitch whose basis has been preserved to this day. There is also evidence of music in Istria. At the end of the 9th century, Glagolitic liturgical singing by priests and laymen was recorded in Church Slavonic. It has survived to this day for some solemn occasions.[40] Another important task was to record the duration of individual notes in a composition. Around 1250, Franco of Cologne invented a system of symbols for the duration of notes. They were written in the form of square signs. [41, 42]

Methods of notating notes were constantly improving. The largest whole note in the Middle Ages was called longa. Later came the name brevis, which is a note duration half that of longa. For faster rhythms, semi-brevis is used, where the duration of the note is only half that of brevis. In the 17th century, everything accelerated even further, and the term "beat" was introduced. This term has remained until today. [43] In 17th-century Italian practice, the concept of tactics (a steady hand strike) was the basis of performance. Although not called "beats", the principle is documented in writings on mensural notation and timekeeping.

During the Ars Nova period in the 14th century, significant innovations in music notation allowed for more precise rhythmic representation. A new note value—the minim—was introduced, shorter than the previously known semibreve, enabling a more detailed structuring of tone durations within a single rhythmic impulse. The system used the terms modus, tempus, and prolatio to describe different rhythmic relationships between note values (Figure 6a). [44] In particular, tempus referred to the division of longer

note values into two or three parts, representing an early form of organising musical beats or pulses. These reforms laid the foundation for the modern concept of the beat as the basic unit of time in music. Beats are usually grouped according to some system, and this is how the measure of a piece of music is obtained (Figure 6b). [45]

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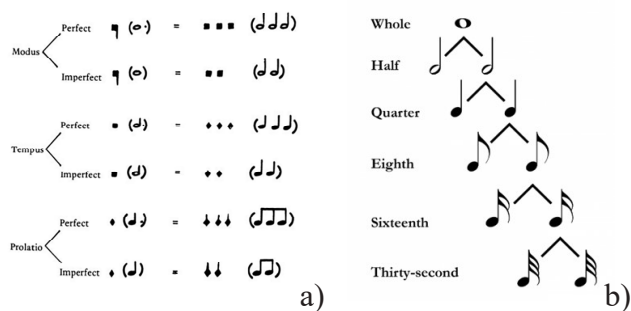


Figure 6 *a) Ars Nova note values, [46], b) Notation of musical notes of different duration values [47]*

In addition to the duration of the tones, the duration and place of the pause in a certain composition are entered. The duration of individual pauses is adjusted to the value of the time duration of the notes on the scale. [48] To make it easier to follow the rhythm, notes and pauses are placed in measures that are enclosed by vertical bar lines (known historically in Croatia as *tinjci*).
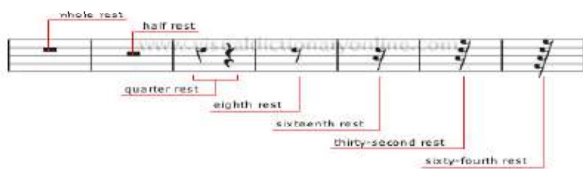


Figure 7 *Display of pauses in the notation system [49]*

The starting pitch of the notes is determined by the selected musical key, and it is entered at the beginning of the line of notes. The most common clefs are the treble and bass clefs, and sometimes the alto clef, and if necessary, some other clefs. To be able to write and correctly place notes higher and lower than the 5-line line, the possibility of additional auxiliary lines above or below that line was introduced. [50]
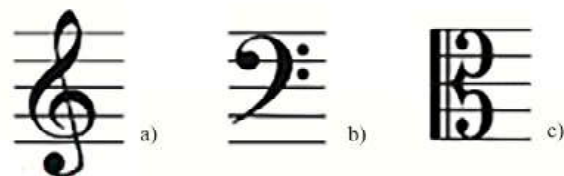


Figure 8 *Graphical visualisation of a) treble or G clef, b) bass or F clef, c) alto or C clef*

In the 13th century, the time signature was written at the beginning of the line, immediately after the clef. This is the duration and content of each measure. [51] For example, 4/4 or 3/4 or 2/4 or some other measure. The lower number indicates the value of the duration of the unit of measure (e.g. a quarter note), and the upper number specifies how many units there are in one measure.

To make the system of notation of music more complete, the tempo of the performance is recorded at the beginning of the movement. Thus, tempos can be slow, such as Grave, Largo, Adagio and the like. Moderate, for example: Andante, Moderato and the like. Fast tempos are, for example: Allegro, Vivo, Presto and many others. [52]

Dynamics (volume of tone) are written below the notes themselves, if necessary. Along with other more precise nuances, we encounter the marking for quiet p (piano), for medium-loud mf (mezzo forte), and for loud music performance f (forte). [53]

## 1.2. Duplication of records of musical works

With a high-quality systematic solution for the exact recording of music, the demand for such recordings is growing. The result is the search for ways to quickly reproduce musical works. Notes and sheet music are filled in by hand, and very beautiful decorations in

many colours as well. One of the ways of duplicating records of musical works was the creation of a printing form by wood carving in China, and Japan (12th - 14th century). [54] In Europe, it was already printed on paper in the 14th century. A further development is the use of a form composed of individual wooden signs. The downside of such a form is that it can only handle a dozen prints. [55]



a)

b)

Figure 9 *Monolithic printing form made of: a) wood [56], b) metal [57]*

At the same time, metal printing forms were already being engraved in the 12th century, but the process for making printing forms for sheet music did not begin to be used until 1586 in Rome. The form for sheet music was made in one piece on a flat surface. [58] This method of preparing musical works for sheet music printing was slow and expensive. However, the quality of prints made using a metal engraved plate was extremely high, so this technology remained in use until the end of the 19th century. At that time, due to the development of photographic technology, sheet music engraving fell out of use.

A special event in the world was the invention of movable metal letters in letterpress printing by Johannes Gutenberg. His first significant work was the printing of the Bible in 1445. Not long after, the printing of musical notes began using movable metal characters, which enabled the printing of larger editions with the same form. [59]

The technological process of sheet music in letterpress was technologically much more complex than, for example, the printing of books. It is difficult to match individual musical notes and their accompanying texts.13 According to New Grove, the first music in a printed edition appeared in 1457. Ulrich Hahn claims that he was the first to print sheet music in 1470. Ugo Rugerius printed from wood in 1497, and Ottaviano de Petrucci in Venice in 1500. [60]

According to various technologies, the text of the song was printed first, and the musical part was written by hand for each printed copy individually. [61] Further development also enabled the printing of horizontal lines, while the notes and vertical lines were written by hand. One possibility was that the notes were finally printed by machine. Thus, 2 to 3 passes through the machine were needed for the printing of musical notes in letterpress. [62] Now the sheet music was legible and transparent, but the printing process took a very long time, so the price of the product was high. With the further development of the letterpress printing technique, the technological procedure became simpler, and the time to make prints shorter while maintaining the high quality of the prints.



Figure 10 *Advanced printing form in book printing [63]*

For inventor and stage artist Alois Senefelder, letterpress and intaglio printing processes for printing plays and music were too slow and too expensive. That's why he experimented looking for

a more efficient printing technique. His invention "lithography", flat printing, was announced in 1796. The working principle is that the free surfaces are hydrophilic, and the printing elements are oleophilic. The printing form was made of stone, so the technique was also called stone printing. [64]

The first printed materials were prints of musical notes. In doing so, a printing system was used in a shutter press, which in 1860 enabled the printing of 20 - 30 prints per hour. In 1811, Fridrik Koenig constructed a machine with a rotating printing cylinder, and this construction enabled a printing speed of up to 400 prints per hour. Commercial production began in Europe in 1825. [65] The great advantage of lithographic printing is the possibility of printing text, sheet music and notes all in just one pass of the paper through the machine. The quality of printing was satisfactory. In lithography, as in letterpress and intaglio printing, printing was done in direct contact between the printing form and the printing substrate.

The rule in printing is that for a high-quality print, one side must be hard and the other soft. At the end of the 19th century, experiments were carried out with a soft printing plate, or cylinder. In America in 1903-1904, Ira Washington Rubel built the first commercial printing machine in which he installed a soft offset cylinder between the hard printing form and the hard printing cylinder. [66] The ink was now transferred from the form to the offset cylinder, and from it to the printing base carried by the hard printing cylinder. The result was excellent print quality. The origin of offset printing dates to that time.

Over time, the stone printing form was replaced by a flexible metal plate that could be wrapped around a base cylinder. In Europe, such a machine with a base, offset and impression cylinder was built by Gaschpar Hermann in 1907. [67] Such a three-cylinder system greatly accelerated the possibility of printing, which of course affected the printing of sheet music for a wide range of users. At the same time, offset reproduction of sheet music became by far the most important until the advent of digital printing. Offset flatbed printing developed strongly. Thus, Caspar Hermann worked on waterless offset from 1926 to 1930. [68] Heinrich

Reuch produced the first special plate for waterless printing. Commercial printing began in 1970 with the 3M plate. [69] Such a plate provides even greater sharpness of the print. Later, three types of plates were developed and produced: photopolymer, silver halide and thermal.

At the end of the eighties, it became possible to go directly to film from the computer during preparation. CtF (Computer to Film) technology is being developed. In the nineties, the trend was to leave out the film and develop the board directly from the computer. It is CTP (Computer to Plate) technology. [70] The results are faster work, precise register, and sharper note prints that are of very high quality. A further development is the generation of printing forms directly in the offset machine (Computer to Press) based on signals from the computer.

Now sheet music can be printed very quickly in any print size and, of course, all in one pass through the machine if necessary and for double-sided printing. It should be noted that the price of prints decreases as the circulation increases. However, such printing forms are not intended for the largest editions, but this does not play an important role in the printing of sheet music, because their editions are generally not very large. At the same time, musicians often prefer the B4 format of printing pads for printing notes over the A4 format, because the record is more legible for musicians and performers.

The next extremely important step is the development of NIP (Non-Impact Printing) technology. These are techniques that print using very little pressure. The only NIP technique that prints completely without pressure is the inkjet technique. [71] The most common techniques for graphic reproduction of originals, which use NIP technologies for printing notes, are laser and inkjet techniques. The first person to patent a mechanical printer for copying an original onto a printing surface was Chester F. Carlson in 1937.

Under the auspices of the Haloid company, later Xerox, in 1950, Carlson created the first photocopier. In 1969, Gary Sterkweather set up the laser printing process at Xerox. Two years later, the company presented the first laser printer to the public. [72] The

printing form is generated anew for each print directly from the computer onto an electrically charged drum. The positive consequence of this is that corrections can be made to the printing form directly from the computer at any time. Similarly, additional runs can always be made without additional costs. The toner (dye) is usually powdered and is transferred to the printing surface by a light touch. [70] The real boom in the laser printer and machine market began around 1980. Today, one of the indicators of print quality is the possibility of 300 to an exceptional 2400 dpi. on the print. 600 dpi is most often used, which is sufficient for very high-quality printing of musical notes. Laser printing is also produced in an offset digital version.80 However, the speed of laser printing is significantly lower than that of conventional offset printing.

Today, inkjet technology is also a very common way of printing. Research began around 1960. The first inkjet printers with a continuous jet appeared in 1970. [73] Piezo inkjet for offices was introduced in 1984. It uses DOD (Drop on Demand) technology. Later, many new inkjet printing technologies were developed. [74] In the 1990s, printing at 300 dpi was considered a great success. Today, there has been significant progress, with print resolutions often reaching 5760 x 1440 dpi for office and home devices. Inkjet technology enables the printing of very high-quality notes. Unlike all other printing techniques that print using pressure or touch, with inkjet there is no contact, but liquid toner (dye) is sprayed from the nozzle directly onto the required places of the printing surface. [75] Since there is no contact with the substrate, this printing technique can use almost all printing substrates. The speed of printing in inkjet technology is significantly lower than printing with laser technology. Also, inkjet prints are more expensive than laser prints.

Over the centuries, musical notation was created and accepted. At the same time, the technology of duplicating the original musical manuscript advanced. There has been a massive digitization of these activities. As a logical continuation, programming languages appeared for recording musical literature on computers. The original can then be prepared on the computer for various needs. A sheet music can be created, edited and played back. From the computer, the sheet music can then be transferred directly to the duplicating machine. Today, the most well-known language for preparing a musical printout for the digital graphic reproduction process is Sibelius.

Despite the significant advantages that digital technology brings to the field of music notation and printing, there are certain limitations that should be taken into account when using it. Digital systems often strive for uniformity in the representation of notated material, which can limit expressiveness and the individual aesthetic approach of the composer or publisher. Handwritten scores sometimes convey nuances of expression, dynamics, or intentional graphic deviations more effectively.

Complex rhythmic structures, microtonal scales, graphic notation, and experimental symbols often require manual adjustments and additional tools, as standard notation software does not support them directly or intuitively.[76] Manual layout allows for intuitive placement of symbols, spacing, and systems, while digital printing often relies on automated layout, which frequently fails to consider proper barline breaks, optimal system distribution, symbol overlap, or the need for page turns—especially in longer scores.

Some users of digital notation systems emphasize that this approach often neglects the personal aesthetic of handwritten scores, which may carry both informational and emotional value. [77] With digital printing, all scores tend to look more similar, which can make it harder to identify the style of an individual composer; for that reason, color is sometimes used to enhance distinction. [78]

Certain limitations are also related to digital printing techniques when using home printers. In such cases, the printed output can be unclear, particularly with small notation symbols, articulation marks, and densely written scores. Details may be lost, affecting readability. Digital printing (especially with inkjet printers) does not always support all types of paper (e.g., heavier weights, textured, or smooth paper used for professional scores), which can influence the durability and overall impression of the printed

score. [79] Inkjet printing may also suffer from ink permanence issues, with prints fading over time or smudging when exposed to moisture. Laser printing is more durable, but not always accessible.

All of the above highlights the ongoing need for further development of digital printing technology in the domain of music notation.

## 2. CONCLUSION

Art is part of the development of homo-sapiens into a civilized person. Since there was no writing in the beginning, knowledge was transmitted using images, and the level of development can be read from the original musical instruments found. With the appearance of letters, attempts to record music began, to preserve it in its original form for future generations. The importance of music can be seen from the fact that it is mandatory to learn music in regular schooling, and from the fact that even the greatest minds of ancient Greece deal with music theory.19 Special successes are the determination of musical notation, musical clefs, and the shapes and values of the notes themselves. At the beginning, at this stage of development, notes are written by hand, and the establishment of the above rules opens the era of graphic machine reproduction of originals. This is where singing and playing come together in time.

The main carrier of sheet music printing was the book printing technique. It was improved over time so that from the end of the 15th century it successfully coped with competition until the second half of the 20th century. Gravure printing also gave its significant volume to the printing of musical works, and until the end of the 19th century, it owed its competitiveness to its special quality. Lithography, born in the late 18th century and improved into offset printing at the beginning of the 20th century, is a printing technique that provides very high quality and speed of printing and has remained to a very significant extent even today. Its competitiveness in the market is also maintained by its successful flirtation with computers, i.e. digital technologies. Today, offset printing is considered to be the most economically acceptable for print runs of over 500 copies, while digital printing techniques are more economically acceptable for smaller print runs. The use of digital printing techniques is constantly increasing today. Various technologies are used, such as sheet-fed printing or ribbon printing. Special printing on tape gradually brings digital technologies into competition with offset printing in larger editions. Special computer programs specialized for such recordings represent a special asset when recording musical works. Their development is of course inevitable because, in addition to the established ways of recording music, different ways better adapted to certain musical aspirations are emerging. It is considered that composers publish about 25% of works, 25% by micro companies, and about 50% by larger publishers. Today, it is considered that the future of the printing of musical materials is most favourable to digital techniques, especially because they, due to their simplicity, can also be used for domestic purposes.

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