Research and reconstruction of art and acoustic cultural heritage by means of optical methods

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Recent advances in science and technology have brought about a diverse range of methods for the scientific research of cultural heritage, and significant developments are being made with all of these methods. This paper introduces the recent research trends in the use of optical methods (a type of scientific research method) for the research and reconstruction of visual and audio artifacts. Particular attention is given to visual artifacts in the form of paintings and sculptures, and audio artifacts in the form of wax cylinder records. As further developments are made in information technology, it is expected that museums and art galleries will compile multimedia databases from a wide range of cultural heritage resources, and optical techniques are likely to play a crucial role in this activity.

Keywords: cultural heritage, museum, art research, reconstruction and reservation, scientific optical method, art and acoustic information, drawing and painting materials, wax cylinder, disk record, multimedia database

1. Introduction

Cultural heritage is generally classified into "tangible cultural heritage" such as paintings, sculptures, craftworks and historical documents, and "intangible cultural heritage" such as Kabuki, Noh and music. Tangible cultural heritage includes archaeological documents, the research of which may also include excavation work. Cultural heritage is thus a wide-ranging field, both in terms of its temporal and geographical scale and in terms of the many different types of tangible and intangible objects included within its definition. Consequently, there are also many different ways in which cultural heritage can be researched and reconstructed. It is therefore difficult to present a comprehensive treatment of the research and reconstruction of all types of cultural heritage. This paper therefore concentrates on tangible cultural heritage that contains visual information (such as paintings, photographs and moving pictures), and intangible cultural heritage that contains audio information (such as spoken language and folk music). Archaeological cultural heritage will not be considered here.

Research into cultural heritage has long since been performed by intuitive methods based on human sensitivity and methods based on historical documents, whereas the introduction of scientific methods only began in the late 18th century. Scientific methods were originally used for the analysis of ancient Greek and Roman coins and the microscopic and microchemical analysis of items such as paintings. In the early 19th century, museums and art galleries in Europe and the United States started to establish their own laboratories for scientific research. Of particular note is the establishment in 1931 of the Louvre Science Laboratory for museums in France. After that, the research of cultural heritage by scientific methods became firmly established, and scientific laboratories became permanent fixtures in museums and art galleries throughout Europe and the U.S. However, these scientific laboratories were invariably used for research associated with visual information such as painting, sculptures and craftworks and were hardly involved in any research aimed at cultural heritage relating to audio information, which was only performed at a handful of museums in Europe and the U.S.

Meanwhile, in Japan—despite the interest shown by a few people into scientific methods—it was only from the 1950s that scientific methods were specifically introduced into the study of cultural heritage. Today, research laboratories that use scientific methods to work on cultural heritage are also permanent fixtures at Japanese museums and art galleries. However, there still do not appear to be any places doing substantial work on cultural heritage relating to audio information.

Recent advances in information technology have revolutionized the research of cultural heritage relating to visual and audio information in museums and art galleries. This has led to developments such as the compilation of databases from all kinds of visual and audio resources, the use of image processing for the measurement and research of artifacts, and new display methods. As a result, cultural heritage is now becoming accessible to (and is receiving greater interest from) the wider public rather than just a handful of researchers.

As a research representative funded by the Ministry of Education, Science, Sport and Culture, Japan, I have studied the optical reconstruction of sound from Piłsudski wax cylinder records (1984–5), and the reconstruction and analysis of audiovisual resources of communities in the China Sea and Japan Sea (1985–6). I was also involved in a study organized by the National Ethnology Museum, Osaka, into northern cultures around Japan based on Piłsudski northern materials (1984–6). I am still involved in the study of cultural assets associated with visual and audio information, and I have followed the development of new techniques for this purpose. In this paper, I will describe some of the new techniques that are available for the research and reconstruction of cultural heritage containing visual and audio information.

2. Cultural heritage containing visual information

The scientific study of cultural heritage containing visual information—such as paintings, sculptures, craftworks and buildings—

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Fig. 1: A bust imaged by X-ray tomography CT

has mainly involved two approaches. One is the study of form, color and materials, such as measuring the age of artifacts and inferring their place of origin by materials analysis. The use of electromagnetic waves (e.g., X-ray and light) is particularly useful in this respect because it allows high-quality measurements to be made in a non-contact and non-destructive manner. As a result, it has no effect on precious cultural heritage, and will probably be increasingly used for research in the future. This section focuses primarily on the use of optical methods for the study of visual artifacts.

2.1 Optical research methods

(1) Neutron beams

Neutron beams are used in autoradiography and neutron radiography to study the construction of craftworks and the pigments in paintings by examining the absorption and capture of neutron beams. Autoradiography uses nuclear reactors and accelerators to produce a beam of neutrons which is directed at a painting to produce an image by means of radiation. It allows the elements contained in the pigments to be studied based on temporal changes such as the half-life of radioactive isotopes in the image.

(2) Gamma rays

Gamma rays are used in gamma radiography and gamma ray CT, in which the absorption of gamma rays is used to study the structure and materials of sculptures, craftworks and the like.

(3) X rays

X-radiography and X-ray tomography CT use the absorption of X rays to study the structure, materials, pigments and the other constituents of paintings, sculptures, craftworks, buildings and so on. Another technique is emissiography, which makes use of the electrons generated when a material is subjected to X-ray irradiation, and is widely used for the study of pigments in paintings and craftworks. X-ray tomography CT, which involves the use of image processing, is becoming a highly sophisticated technique.

Figure 1 shows images obtained by X-ray tomography CT of the outer surface (left side view) and inner surface (right side view) of a herm restored in Rheinisches Landesmuseum Bonn in Germany, which was found in a shipwreck near Mahdia, Tunisia.[1)]

(4) Ultraviolet light

Ultraviolet light is used in UV reflectography and ultraviolet fluorescence analysis, which uses the optical (visible-light) luminescence produced when an object is illuminated with ultraviolet light. Both of these techniques are used to study pigments and dyes in paintings.

(5) Visible light

Techniques that exploit the absorption and reflection of visible light include stereo microscopy and laser microscopy, which are used to investigate the shape, materials and production methods of paintings and craftworks. Also, polarizing microscopes (which use polarized light) can be used to investigate the mineral nature of sculptures and buildings. Recently, techniques that involve the use of interference phenomena of the laser light, such as holography, holographic interference techniques, electronic speckle interference techniques and moiré topography (which uses optical moiré patterns) have been used to analyze the deformation of paintings and to analyze and record the three-dimensional shape of sculptures and craftworks. It is likely that laser measurement methods using the properties of laser light will be employed increasingly for the study of cultural heritage containing visual information.

(6) Infrared light

These techniques, such as IR reflectography, IR transmittography and infrared photography, principally use the absorption and reflection of infrared light to investigate and study the underlying sketches in paintings. Also, thermography, which uses the thermal emission of infrared light, is used to study the structure of buildings. An infrared reflectography system is an infrared image sensor consisting of a monochromator for illumination, an infrared Vidicon, and a silicon CCD camera, and is sensitive to a wide range of infrared wavelengths from 300 to 1800 nm. Accordingly, infrared reflectography is able to see through the surface grime and upper paint layers that cover the underlying sketches in a painting, thereby revealing hidden information.

Figure 2 shows an infrared reflectography of "Christus am Kreuz" painted in 1503 by Lucas Cranach (1472–1553), a well-known German artist of the Renaissance period. Here, a carefully composed underdrawing can be seen.[2)]

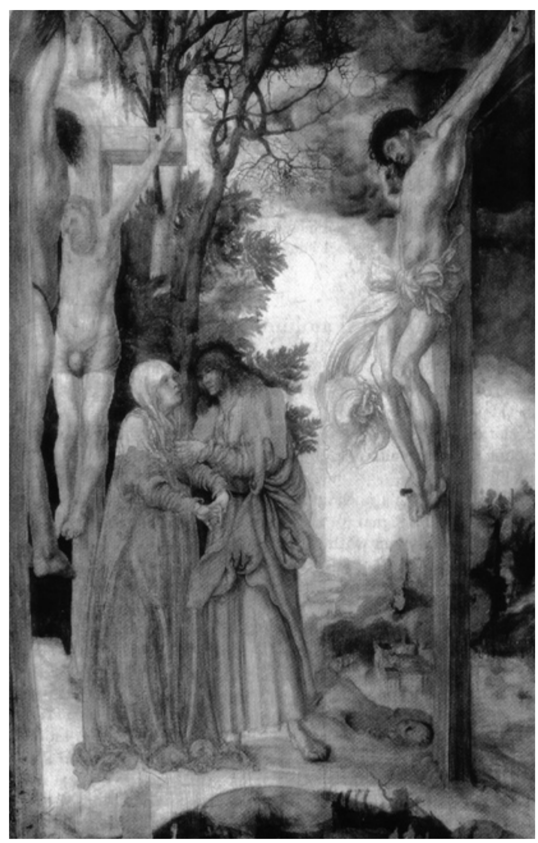

Fig. 2: An infrared reflectography of "Christus am Kreus" by Lucas Cranach

Fig. 3: Interference pattern over a head statue obtained by the holographic interference method

2.2 Research and reconstruction of cultural heritage by optical methods

Over the last half-century, these optical methods have become common techniques for the study of cultural heritage and have diversified along with the widespread progress in science and technology. In the future it is likely that many more methods will be developed. The importance of these methods, and the way in which they relate to the research and restoration of cultural heritage, are discussed below taking paintings as an example.

Paintings are generally built up in a sequence of layers consisting of a supporting material, a filler, an undercoat, paint, and varnish. The supporting material (also called the base material) performs the role of supporting the undercoat and paint that make up the painting. The filler forms a layer between the supporting material and the undercoat, and its purpose is to adjust the surface of the supporting material before the undercoat is applied. The undercoat smooths out the surface of the supporting material, and improves the coloration and bonding properties of the paint, which is applied on top of the undercoat. The paint consists of pigments and a color development agent, which is an organic adhesive that forms a paint when combined with pigments. Pigments can be either inorganic or organic, and may consist of various different materials including natural pigments and artificial pigments−the range of artificial pigments has grown rapidly since the late 18th century. Finally a layer of varnish is applied. This covers the surface of the painting with a transparent film which provides the paint with a feeling of luster and transparency, and prevents discoloration and fading of the paint.

This multi-layered structure is kept in a fine balance. An old master that has existed for many years may suffer from all kinds of problems, such as deterioration of various materials, warping of the paint layer due to deformation or deterioration of the support, peeling of the undercoat and paint associated with reduced adhesion, and discoloration or color fading due to exposure to the atmosphere. Such paintings have often been restored numerous times and sometimes look completely different from the original painting, making it necessary to thoroughly investigate the original picture. From an art historian's viewpoint, the study of the techniques and materials used in art is a subject of great interest. It is thus important to undertake an accurate comparative investigation of the original image and the image after reconstruction.

Scientific research into the problems of important paintings is essential, and it is especially important to use a non-contact and non-destructive approach. For this reason optical methods are particularly promising. Examples of such methods include the use of transmission X-ray photography to study painting techniques and discover hidden pictures (double layered paintings), the study of pigments by emissiography, the identification of materials by ultraviolet fluorescence detection, and the observation of underlying sketches by infrared light as described above.

Although the research and reconstruction of cultural heritage are important starting points, the next important issue is their preservation. Furthermore, although it is of course essential that important cultural assets are kept for a long time, it is also important to exhibit them as the heritage of all people. From this viewpoint of preservation and exhibition, holographic techniques−whereby a three-dimensional image is obtained in a complete form−are essential scientific methods for the recording and exhibition of cultural assets. Holography is a technique which uses the diffraction and interference of light to record all the information of an object as an interference pattern, and for reproducing it three-dimensionally in its complete form. Accordingly, paintings, sculptures, craftworks and the like can be recorded in holograms and faithfully reproduced three-dimensionally. It is therefore a kind of replication technique, since the reproduced images are the same as the real artifacts. By exhibiting holograms of cultural assets instead of the real thing, it becomes easier to exchange cultural heritage over the whole world.[3)]

Research into the use of holographic techniques to record and exhibit cultural assets was initially conducted at establishments in the former Soviet Union, such as the Institute of Physics, Ukrainian Academy of Sciences, but today precious cultural assets are recorded in holograms and used in exhibitions in countries all over the world, including Europe and the United States.

Holographic techniques are also being used for the reconstruction and preservation of cultural assets such as paintings and sculptures in all European countries, especially Italy. Holographic interference techniques and electronic speckle interference techniques are used for this purpose. Specific examples include the detection of internal defects in paintings, such as warping of the paint layer associated with deformation of a painting's support and peeling of the undercoat and paint, the detection of deformation associated with temperature changes as a preliminary step to the reconstruction of sculptures and the like, and the precise measurement of erosion in artifacts.

A group at Universita degli Studi de L'Aquila in Italy has developed a system that automatically measures the shape of an object's surface based on both sandwich holographic interference methods and electronic speckle interference methods, and have obtained numerous interesting results in their studies of erosion and cracks, such as cracks in paintings and sculptures.

Figure 3 shows an interference pattern superimposed on a painted wooden head statue with cracks[5,6] (16th century, part of the L'Aquila Museum collection) imaged by the sandwich holographic interference method.[4] There is a visible shift in the position of the interference pattern on either side of a crack in the upper part, which indicates that there is a difference in height between the two sides. The study of cultural heritage by this sort of holographic interference method is particularly commonplace in European museums.

3. Cultural heritage containing audio information

Cultural heritage that contains audio information–such as spoken language and folk music–includes recording media such as old-fashioned music-boxes, records and cassette tapes. Recently the appearance of digital media such as CDs has made it possible to record and reproduce sounds with high fidelity. However, the records of interest in terms of cultural heritage include music boxes, wax cylinder records, disk records, and more recently tape records. Of these, music boxes are craftworks that are important items of cultural heritage but are mechanically complete and do not degrade mechanically over long periods of time, and have been preserved in a nearly perfect condition. Accordingly, there are no problems with reproducing the recorded sound information, which is generally music. On the other hand, wax cylinder records and disk records remain in great numbers principally in Europe and the United States, and contain precious sound information such as spoken language and folk music, making them an important part of the heritage of cultural anthropology. Due to the relationship between the materials used in wax cylinders and disks and the environments in which they are placed, wax cylinders and disks are usually in an advanced state of degradation and are often found to be broken. We therefore need scientific techniques for the research and reconstruction of audio artifacts, especially wax cylinder records. In this section I will introduce the research into the optical reproduction of sound from wax cylinder records, and I will also describe a few related issues.

3.1 Wax cylinder records[7,8]

The records that were widely used around 1900 were of two types: cylinders and disks. Cylinder recording began in 1877 with the invention of the tin foil phonograph by Thomas Edison, and was improved by the introduction of wax cylinders. On the other hand, the disk format was devised by Emile Berliner in 1887, and is the prototype of modern records. In addition to the different shapes, these formats also differed in terms of the way in which sounds were recorded–on cylinders, the vertical depth of the sound grooves corresponds to the strength of the sound signal, whereas in a disk recording the sound signal is represented by the amount of horizontal displacement of the sound grooves.

Cylinder records are made of tin foil, wax or plastic, but wax was the most widely-used material. This material principally consisted of stearic acid, which was mixed with sodium hydroxide, paraffin and aluminum oxide, resulting in a mixture closer to soap than wax. A standard wax cylinder measures 55 mm in diameter and is 105 mm long, and has grooves cut into it in a helical fashion with a pitch of about 100 lines per inch. This is rotated at 160 rpm, and is thus capable of recording about 2 minutes of the sound. These recordings were produced in the era of acoustic recording, where the sound was collected from a horn and the energy in this sound was used to cut the surface of the cylinder with a stylus. The grooves in an ordinary cylinder have 50 μm maximum depth, although in early recordings the maximum depth may be as little as 10 μm. The frequency characteristics of sounds reproduced by wax cylinder phonographs cover the sound range of 500 Hz–3.5 kHz, which reflects the frequency characteristics of the horn. Figure 4 shows some wax cylinders (on the left) and their cases (on the right), and shows how wax cylinders are rather deteriorated.

Fig 4: Wax cylinders and cases

One of the properties of wax cylinder phonographs was that they allowed recordings to be made easily. Since the Edison-type phonographs could be used to make recordings simply by changing the stylus, it seems that they were often used not simply as sound reproduction equipment but also as a useful recording tool for people with an interest in music and sound, in much the same way as tape recorders are used today. Historically, wax cylinders disappeared in a short time, but since they were manufactured in their millions there must be many still in existence today. Most of them were used to record music, but some of the wax cylinders recorded by individuals are of great interest to linguists and anthropologists, or as records of the speech of famous people of the time.

However, wax cylinder records are generally stored in adverse conditions, and many are found to have surface defects arising from denaturing of the wax, scratches, scrapes, and adhered foreign matter, and they are often found to be cracked or broken. It is thus often impossible to reproduce the sounds using the original phonographs. Considering this, as a preliminary stage to the reproducing operation the surface of the wax cylinder is cleaned and broken parts are restored, and replicas are also made in order to preserve the wax cylinders for the future. In the restoring process, it is washed with degrading enzymes to remove crystallized substances, and broken parts are glued back on under a stereo microscope. A replica is then produced by making a mold with dentists' silicon impression material, into which the epoxy resin used in electron microscopy is poured.

After the restoring work has been completed, the sound can be reproduced. If the wax cylinder is in good condition it can be

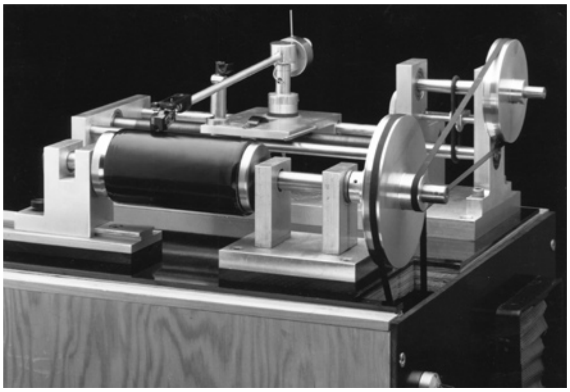

Fig. 5: A stylus-type wax cylinder machine made by the National Museum of Anthropology in Canada

reproduced using the original phonograph. However, since acoustic recording and reproduction were the only techniques available in Edison's time, a heavy stylus pressure of 20 g is required, and if the reproduction is conducted using the original phonograph there is a danger that the surface might be scratched by the stylus. Considering this, special reproduction equipment for wax cylinders is being developed in museum laboratories to replace the original phonograph.

Figure 5 shows a stylus-type sound reproduction machine for wax cylinders which was produced at the National Museum of Anthropology in Canada.[9] Machines of this sort generally use either a sensor for the measurement of surface roughness or an audio vibration sensor, and in either case the stylus pressure is made extremely small to suppress the effect on the surface, and the sound grooves are measured with high sensitivity to reproduce the sound signal. However, when a wax cylinder is in poor condition, it is much better to use an optical reproduction method using the laser in a non-contact manner after the restoring work has been completed. Optical reproduction methods of the sound are discussed below.

3.2 Laser beam reflection method[7,8,10,11)]

The laser beam reflection method is the basic optical sound reproduction method, and the principle behind this method is illustrated in Fig. 6. As mentioned already, the sound grooves on the surface of a wax cylinder are recorded as signals of varying depth. Therefore, if a wax cylinder is illuminated with a narrowly-focused beam of light as a probe, the reflected light will have an angular modulation caused by the inclination of the sound groove, and it is thus possible to reproduce the sound by detecting this angle. The beam reflected at the surface is converted into a sound signal by a position detector located in the detecting plane. The detecting signal is proportional to the inclination of the sound groove, i.e. the differentiated sound signal, so it can be integrated to obtain the depth of the sound groove, thereby converting it into the sound signal. Figure 7 shows a laser beam reflection-type sound reproduction system.

As a result of investigating the reproduced sound obtained with this method, it was found that further study is required to study various problems, including noise, echoes and tracking errors. The beam reflected from the surface of the wax cylinder is superimposed with speckle noise, which results in characteristic noise being added to the reproduced sound. This noise can be reduced by adjusting the spot size of the illuminating beam used as a probe, but it is impossible to completely eliminate the speckle noise. However, the noise can be reduced by an electric filter since the characteristics of this noise are known. The echo that appears in the reproduced sound arises due to the simultaneous illumination of adjacent grooves by the illuminating beam. It is therefore essential to adjust the spot size of the illuminating beam so as to track a single sound groove reliably. Furthermore in the optical reproduction method, since we are not tracking the sound grooves directly with a stylus as in the stylus method, it is prone to tracking errors due to undulations in the sound groove on the wax cylinder or position errors of the driving part in the reproduction system. When tracking errors occur during reproduction of sound from the wax cylinder, the volume of the reproduced sound drops sharply and it is not possible to reproduce the sound from the entire wax cylinder stably. This problem can be solved by employing a scheme whereby a two-dimensional position detecting device is used to detect tracking errors separately from the sound detection, and corrections are made by feeding the tracking error signal to the driving device (see Fig. 6).

In addition to the above problems, in order to eliminate stray light, a scheme is employed whereby an optical focusing system is inserted into the light path of the reflected beam and a pinhole is positioned at the fo-

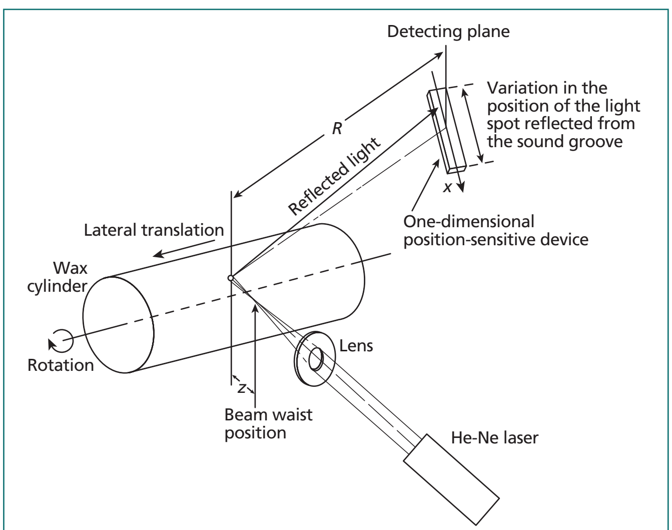

Fig. 6: Principle of the laser beam reflection method

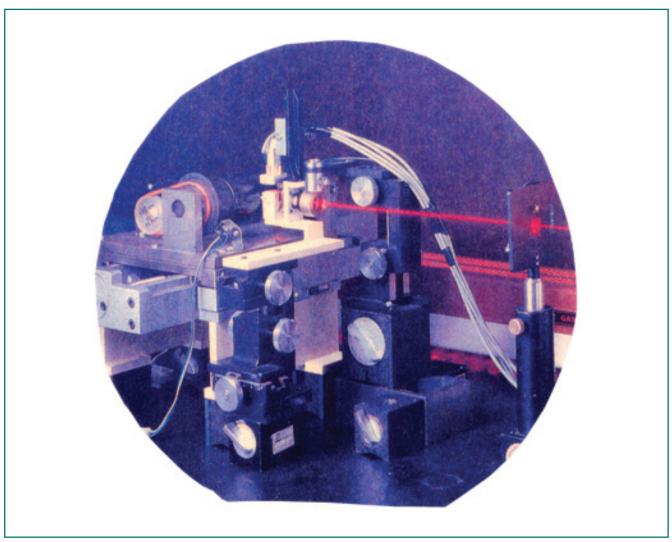

Fig. 7: A laser beam reflection- type sound reproduction system

Fig. 8: A negative cylinder

cal plane to eliminate stray light, after which detection is performed. Also, to eliminate the noise originating from the speckle phenomenon, the use of incoherent light from an infrared light-emitting diode instead of a laser light source is also being tried out. However, this approach suffers from problems with adjustment of the optical path because the infrared light is invisible to the naked eye.

3.3 Reproduction of sound from negative cylinders[8,12,13)]

It has recently come to light that the National Museum of Anthropology in Berlin is in possession of large numbers of wax cylinders with recordings of the folk music of various countries in the world, as well as cylindrical metal "masters" that have been duplicated from them. These metallic cylinders (see Fig. 8) are called negatives or Galvanos (in the following they are referred to as negative recording cylinders or negative cylinders). It used to be possible to produce duplicate wax cylinders by using a negative cylinder as a master, but this duplication technology has now been lost. In any case, the production process would involve melting the original wax cylinders, which would be irretrievably lost. Reproduction of sounds directly from a negative cylinder is not easy either. It is essentially impossible to reproduce sounds with a stylus because the sound information is recorded on banks (ridges) on the inner surface of the cylinder. However, optical methods that use laser light do not need to make mechanical contact with the recorded parts, and it should therefore be possible to reproduce sounds from negative cylinders in the same way as wax cylinders.

Figure 9 shows a prototype sound reproduction machine for negative cylinders. The reproduction machine consists of two parts: a drive unit on the left and a control unit on the right. Figure 10 shows a schematic diagram of the overall machine configuration. The drive unit comprises an optical head, which incorporates an optical system that detects the signal, and a drive section that rotates and moves the negative cylinder. Figure 11 shows a schematic diagram of the constructed optical head. The optical head is inserted into the negative cylinder, which is attached to a cylindrical holder, and detects the signal recorded in the banks of the protruding sound track. The negative cylinder is fixed with screws to the interior of a large cylindrical holder. The cylindrical holder is able to rotate, and is driven by a DC motor M_1 via a belt and pulleys. A circular disk with radial slits is attached to one end of the holder, and a pulse signal whose frequency is proportional to the rotation speed of the holder is obtained by detecting the slits with a transmitting type photosensor. The holder and DC motor are attached to an X-stage mobile platform which is driven by a pulse motor M_2. On the other hand, the optical head is fixed to an XYZ-stage, whereby its position on the inside of the negative cylinder can be adjusted in three dimensions by the stage micrometers, allowing the optical head to be positioned at the optimal location. At the optical head, the light focused by a lens is directed at the recording surface of the negative cylinder at an inclined angle, and the reflected light is received by a position-sensitive device PSD. The output signal from the optical head is guided to a control unit, and is split into two signals corresponding to the two coordinates of the PSD plane in a signal converter. One of the two signals is the sound signal, and the other is a tracking signal. The sound reproduction is from the sound signal, and the tracking signal is

Fig. 9: A reproduction machine for negative cylinders

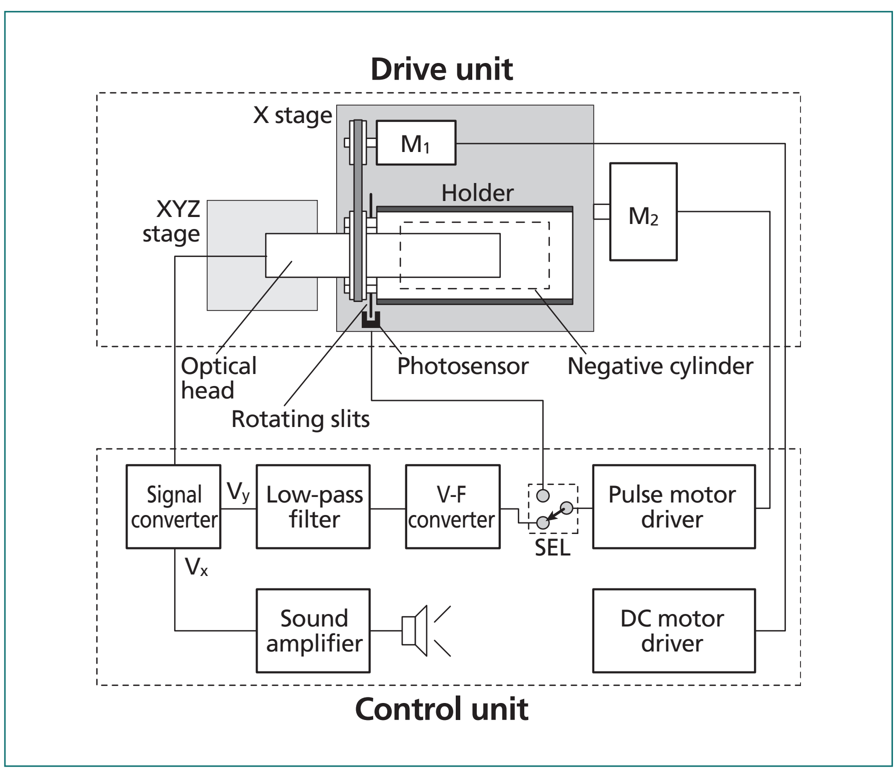

Fig. 10: Diagram of the reproduction machine

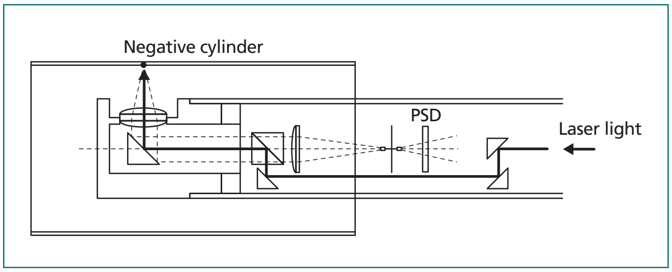

Fig. 11: Schematic diagram of the optical head

used for automatic tracking.

In general, sound reproduction from negative cylinders produces better sound quality than from ordinary wax cylinders. This is thought to be because the negative cylinders were produced straight after the sound recording had been made on wax cylinders, whereas the wax cylinders that exist today have been played back many times in phonographs with a large stylus pressure.

3.4 Disk records[8,14)]

Although disk records are made of materials that in themselves are less prone to deterioration, they also crack more easily and are often broken (see Fig. 12). It is expected that optical methods will be useful for reproducing the sound from disk records of this sort. As mentioned above, the sound grooves in a disk record vary within the plane of the record, and the sound information is recorded as a horizontal variation of the sound grooves. This makes it impossible to employ the laser beam reflection method used for wax cylinder records. Therefore, another reproduction method has been developed that exploits the diffraction phenomenon of the laser light by the sound grooves.

When the sound groove of a disk record is illuminated with a laser beam and the reflected light due to diffraction is observed, it can be seen that the horizontal variation of the sound groove affects the reflected light. If the spot size of the laser beam is similar to the width of the sound groove, then it is possible to regard roughly the sound groove within the illuminated region as being a line. If this sort of line region is illuminated with a coherent laser beam, the diffracted light reflected from it will also have a linear structure together with the central specular spot. Furthermore, the linear structure of this diffracted light is perpendicular to the direction of the straight line of the illuminated sound groove. Accordingly, as Fig. 13 shows, it is possible to detect the local direction of the sound groove by considering the direction of the line pattern in the diffracted light. In this way, it is possible to reproduce sound from disk records by a laser diffraction method. However, this method is only applicable to monaural recordings, and it is much more difficult to track the sound groove with the laser beam than in the case of wax cylinders.

3.5 Use of optical fibers for sound reproduction[15)]

Since stylus-type sound reproduction methods wear down the sound grooves, the improvement of stylus methods has received little consideration. However, since a stylus is the best way of tracking the sound groove, it is the most suitable method from the viewpoint of sound quality. Since it is now possible to employ electronic amplification means, it is conceivable that stylus-type sound reproduction with a very small stylus pressure may prove to be an effective method. Research in this direction has been performed using optical fibers.

One such method is implemented by the system shown in Fig. 14. Laser light is focused by a microscope objective lens and guided into one end of an optical fiber. The optical fiber is fixed at a fulcrum close to the other end, and a stylus which tracks the sound groove is attached near the end of the fiber. Since the stylus tracks the variations in the depth of the sound groove, the light emerging from the end of the optical fiber changes direction according to the variations in depth. An optical focusing system is used to focus this onto the detection plane of a position-sensitive device. Accordingly, the output of the position-sensitive device differs from that in the case of the laser beam reflection method, and an electrical signal is obtained according to the variations in depth of the sound groove, which can be amplified electronically to reproduce the sound.

Another method does away with the stylus and uses the optical fiber itself as a stylus to follow the sound groove as illustrated in Fig. 15. Here, the core of the optical fiber is used as a mechanical guide for the sound groove. Using an optical fiber with a core diameter of 150 μm, it is possible to track the sound groove using the edges of the sound

Fig. 12: Disk records

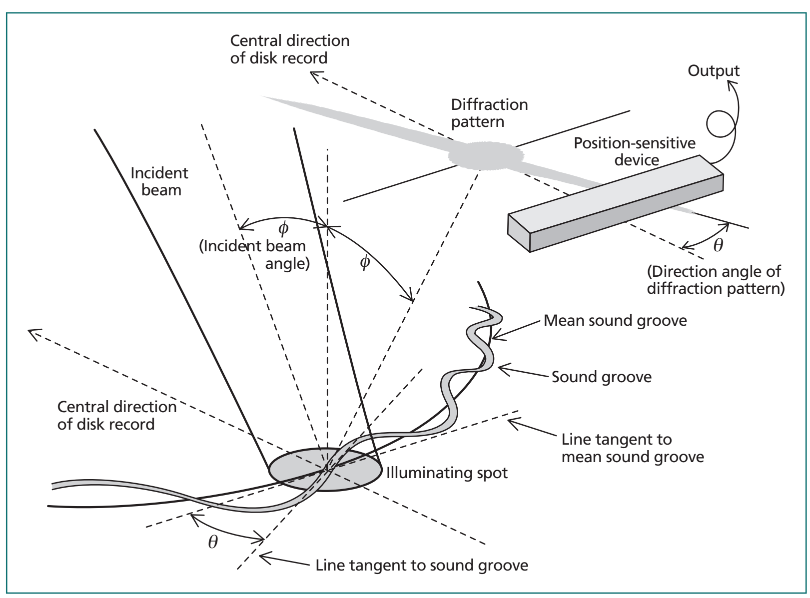

Fig. 13: Principle of the laser diffraction method

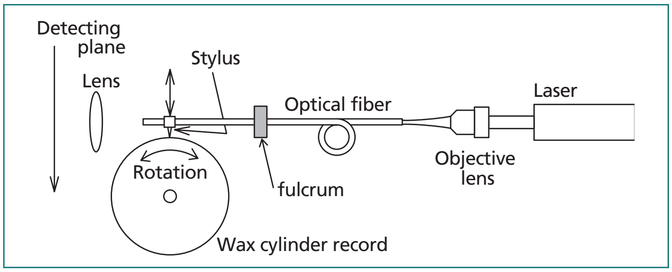

Fig. 14: Stylus-type sound reproduction method using an optical fiber with a stylus

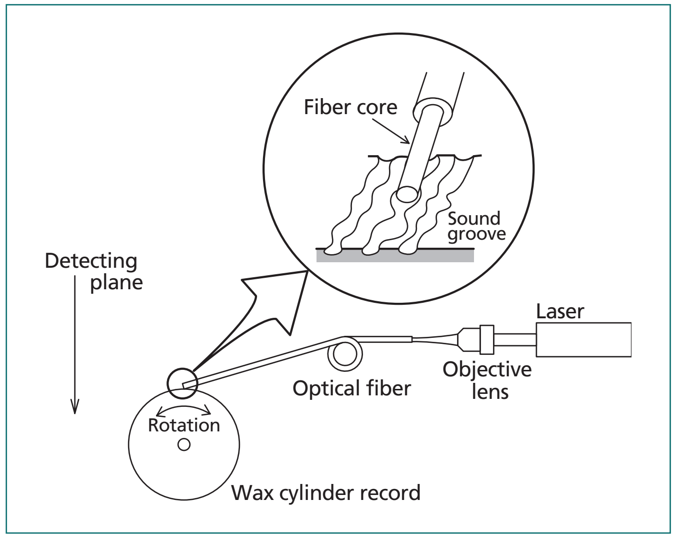

Fig. 15: Contacting sound reproduction method using an optical fiber without a stylus

groove as guides. In this case, the core is separated from the bottom of the sound groove, and the light emerging from the optical fiber illuminates the bottom of the sound groove under a slightly diffusing illumination condition. The light reflected from the sound groove propagates toward the detecting plane and is incident on the position-sensitive device. Accordingly, this method solves the problems of tracking errors and the size of the illuminating light spot that have occurred in the laser beam reflection method. However, since it involves the use of a laser light source, it still suffers from the problem of speckle noise as in the laser beam reflection method. Furthermore, since the optical fiber is made of quartz, which is much harder than the wax cylinder material, it results in slight wear at the edges of the sound groove during reproduction. Since the sound is recorded at the bottom of the sound groove, this is of no direct consequence, but from the viewpoint of non-destructive sound reproduction there is much scope for improvement.

4. Conclusion: Multimedia databases

Visual and audio cultural heritage is generally kept in museums and art galleries, which inevitably have to deal with large volumes of visual and audio information. In practice, they have to deal with masses of photographs, slides, moving pictures such as videos, and audio recordings such as spoken language and folk music. They may also need to maintain photographic records of every artifact from every angle, and may use image processing for the automatic measurement and retrieval of specimens by size, shape and/or color. Databases can be compiled by digitizing this information, and integrated systems are now under development that will bring all of these activities together.

Although museums and art galleries are a type of research laboratory, at the same time they are generally required to put on exhibitions. In this case, it becomes necessary not only to exhibit suitable specimens, but also to provide video displays and spoken commentaries, and to find ways of visualizing things that cannot be seen. New optical methods such as high-definition TV, holography, computer graphics and virtual reality can prove very useful for such purposes.

As information technology continues to advance in the future, it is likely that museums and art galleries will be called upon to shoulder an increasingly diverse range of responsibilities relating to the preservation and presentation of audiovisual heritage, and optical methods will probably play an increasingly important role in their work.

In this paper, I have summarized the research and reconstruction of visual and audio cultural heritage by optical methods based on very limited materials. But even within this limited scope it is difficult to collect and summarize the wide range of this field, both in terms of the range of activities associated with visual and audio cultural heritage, and in terms of the geographical location of such cultural properties which are spread all over the world. However, as science and technology progress, it is certain that scientific methods for the research and reconstruction of cultural heritage will continue to progress and diversify. I hope this brief introduction will stimulate the reader's interest in this interesting field.

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