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Successful Development of a “Mirror” to Form 3-D Floating Images

The World of Science Fiction

In a common scene from science fiction, a true-to-life 3-D image appears above a table out of thin air. However, development of the corresponding technology in the real world presents enormous challenges, and so the device has to date remained in the sci-fi realm. Past systems selectively used multiple 2-D images and the parallax effect to attempt to arrive at 3-D images. These were not true 3-D images, however, yielding only limited success in conveying the sensation of an object actually present.

In our present study, we have succeeded in the development of a “mirror” to form a 3-D image in space that relies on a simple target-imaging process.

Properties of a Mirror Image

When we look in a normal mirror, we see our own figure and the objects around us. What happens when we try to reach out and touch our body or an object in the mirror? Naturally our hands meet the surface of the mirror; the objects within are out of reach. This is because the image in the mirror is not a “real image” created by the concentration of light in a volume of space, but rather is a “virtual image” created by the bending of light on the mirror surface, giving the appearance of objects that lay behind.

A so-called “mirror image” has the following properties.

1) It displays plane symmetry to the object respective to the mirror plane, and three-dimensional magnification is the same in all directions, even in the direction of depth.

2) The front and rear of the object are reversed due to the plane-symmetrical transformation.

Due to these properties, a mirror image is able to provide an extremely clear 3-D image with no distortion. A look in any mirror will confirm this: the world we see looks exactly like the world we live in except for the front and rear direction. However, as explained above, a mirror can only create a virtual image. In contrast, convex lenses and concave mirrors are examples of imaging optics that can create what we refer to as a “real image.” With these sorts of images, however, the appearance of the target is enlarged or reduced in magnifications that depend on the distance between the optics and the target. For this reason it is a technically difficult task to generate an undistorted 3-D floating image.

The Newly Developed “Mirror” (Imaging Optics)

The new “mirror” developed by our group is unlike a normal mirror described above. Instead, it is a special passive imaging optics made using nano-fabrication technologies, and in fact consists of numerous micro-mirrors on the optics surface.

This structure allows the mirror image to be viewed as though seen from the opposite side of the mirror, as if you are in the mirror. As a result, 3-D objects are reversed in terms of depth. The present imaging optics enables the formation of a “real” mirror image, presenting clear, undistorted images of a type previously impossible to produce in common optics systems. This means that there’s no distortion in physical relationships in the 3-D image — not only when viewed from a single angle but also when viewed from several different points of view (Fig. 1).

Fig. 1

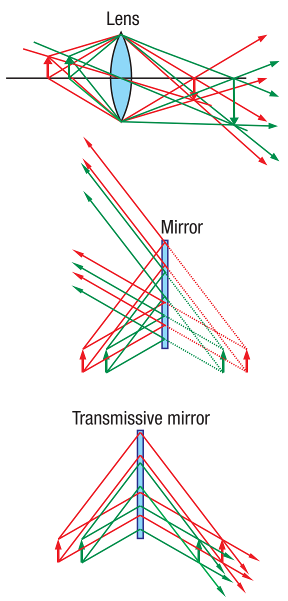


Fig. 1. Comparison of methods of image formation: convex lens (top), mirror (middle), and imaging optics developed by our group (bottom).
The convex lens has a central optical axis, and the imaged object is enlarged or reduced depending on the distance from the lens to the object. This lens can form real images. The mirror, on the other hand, lacks an optical axis, and forms a plane-symmetrical image at 1:1 magnification. The dashed lines show the virtual light beam, and the image formed is virtual. Here we can see that the developed optics creates the same image formed by the mirrors, except that it does so as a real image.

Structure and Principles of Operation

The main design feature of the developed imaging optics is seen in its array of numerous dihedral corner reflectors consisting of minute micro-mirrors. A dihedral corner reflector is comprised of two mirrors placed at right angles to each other, and light is reflected recursively in the plane formed by the perpendicular lines of each mirror. You can see this effect by looking into two mirrors placed perpendicular to each other. You will find that your face always appears in the center. Light from a point source reflected by a planar array of such dihedral corner reflectors will always pass though the position of plane symmetry, resulting in a real image of the point light source. In

Life and Technology

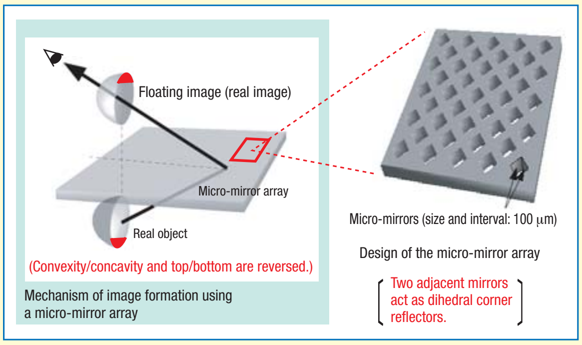
Q: Various types of floating image displays have been proposed in the past. How is the present imaging optics different from the others?

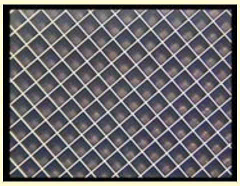
A: The imaging optics developed is not a display system by itself. The optics is just passive and simply a thin plate, much like a mirror. In order to create a floating image, any object needs only to be placed behind the plate, and the optics itself doesn’t require power to work, although lighting is of course required.

the developed imaging optics, square openings were drilled in metal element substrates, and the two adjacent interior surfaces of the opening were used to form the dihedral corner reflector (Fig. 2). This basically explains the optics structure, and although this structure is a simple one, actual production is extremely difficult, since each micro-mirror is only 100-μm square. Further, the mirrors cannot be polished since their surfaces must be perpendicular to the element surface. In the present study, these problems in producing the optics were overcome with the application of nano-fabrication technologies.

The developed imaging optics must allow light to pass through, even with the employment of the micro-mirrors. An optics constructed in this way allows the light beam to be bent at the optics surface at acute angles, relying on mirror reflection as the principle of operation. The image formed may thus be viewed from angles oblique to the optics surface, and a floating

Fig. 2.

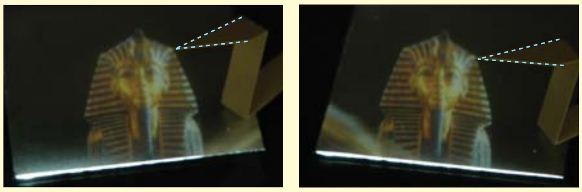




Enlarged photograph of element

image can be generated above a horizontal tabletop. Figure 3 shows a floating image as actually observed.

Fig. 3.



A floating image formed above the “mirror”: Image observed from the left (left) and from the right (right). The arrow on the right is a real object seen on the “mirror.” Note how its position relative to the image does not change even when viewed from different angles.

Expanding Application to A Variety of Fields

Let’s look at an interesting example of how this optics can be applied. A mirror can reflect anything, including other mirrors. The image of the mirror enters the mirror reflecting it. Further, it’s possible to see your image in the mirror that is itself reflected in the first. If you tried this using normal mirrors, your image would always remain confined in the mirror. What happens when our newly developed mirror is used as the first? Since our mirror lets light pass through, the second mirror to be imaged by ours will be viewed from the opposite side, but from the same side as with normal mirrors. Surprisingly, the image of the second normal mirror will float out in front of our mirror. Naturally, in principle, it is possible to see an image of yourself in the floating image of the second mirror. If the second mirror is correctly positioned to float, then your image will also float. In other words, when you look into our magic mirror system, you will be able to see a floating image of your own face.

Given the characteristics described above, the optics developed in our study has the potential to be applied in a wide range of areas, such as the development of new display devices for realistic 3-D floating imaging technology, as well as a host of entertainment fields.

ny issues remain to be resolved, such as increasing resolution, eliminating stray light, and reducing costs, but we are hopeful that in the future, this magical “mirror” will be as common in homes as conventional mirrors are today.

This month’s key concept

[Floating Image]

A floating image is an image formed in three-dimensional space; you can extend your hand into the space in which the image is seen. In optics, such images are called “real images.” Note that the term “floating image” simply means that the image is formed in space, appearing to float, regardless of whether the image is two-dimensional or three-dimensional. However, even with 2-D images, it is possible to convey a three-dimensional impression, since the object will appear to float at a fixed position in 3-D space. The imaging optics developed by our group causes undistorted 3-D images to float in the air. The result gives a peculiar effect, since the image occupies space visually, but not physically. Furthermore, since it is only an image, it is not governed by the physical laws that affect objects, and this freedom is likely to prove exceptionally effective in advertisement and entertainment applications.

Researcher

Satoshi Maekawa
Senior Researcher, Universal City Group, Knowledge Creating Communication Research Center, Research Department 2

After having completed his graduate course and his years as a JSPS (Japan Society for the Promotion of Science) Fellow, he joined the Communications Research Laboratory (currently NICT) in 1998. He mainly pursues studies in the fields of bio-signal processing, evolutionary and adaptive systems, and cognitive psychology. Ph.D. in Engineering.

Visit

Do You Know This Facility at NICT?

NICT has a variety of experimental instruments and facilities that are essential to our research activities. In this series, we will introduce some of these unique instruments and facilities.

Applying Cognitive Information to Future Communication Technologies

— A Visit to the Kobe Advanced ICT Research Center (KARC) —

Why Are There Medical Instruments at NICT?

At the Kobe Advanced ICT Research Center (KARC) in Kobe City, a variety of research activities — including investigations in biotechnology, brain studies, nanotechnology, superconducting technologies, and quantum and laser technologies — are underway, in line with the Center's role as a hub of basic research carried out by NICT (Photo 1). Projects at KARC include studies focusing on physiological information relating to the human body. In the present issue, we report on a visit to the Biological ICT Group, which carries out R&D on the "visualization" of brain information using state-of-the-art measuring instruments that reveal the activities of the human brain, in addition to studies of technologies designed to put this brain information to use.

Studies on Human-Friendly Brain-Measurement Instruments

Diagnostic devices using X-rays are well known in the medical field. As an alternative, however, current integrated research efforts are being applied to the development of safe, secure, non-invasive visualization instruments, which will eliminate the potential hazards of exposure and require no contrast media. The Biological ICT Group is currently working to make progress in technologies to measure brain information, such as the technologies involved in fMRI*1 (for "functional magnetic resonance imaging instrument"), MEG*2 (magnetoencephalography scanners), and NIRS*3 (near-infrared spectroscopy), as well as studying methods for the extraction of information through the combined use of these devices. While the diagnostic instruments we normally see at medical facilities are designed for pathological examinations, NICT's efforts to develop and devise uses for new instruments are more broadly aimed at human-friendly and comfortable communication technologies. These efforts are based on detailed study of the information-processing characteristics of the human brain.

Photo 1. A variety of research activities are conducted at the Kobe Advanced ICT Research Center (KARC) in Kobe City—biotechnology, brain studies, nanotechnology, superconducting technologies, and quantum and laser technologies, to cite a few.

Development of the Next-Generation fMRI

Wing 3 of KARC holds a magnetically shielded MRI room that in turn houses a 3.0-Tesla high-field MRI instrument (Photo 2-1). MRI is the acronym for magnetic resonance imaging, and represents a method of imaging cross-sections of the human body using nuclear magnetic resonance phenomena, mainly associated with the hydrogen atom. In recent years, we are seeing more and more health-screening packages with "MRI brain examination" included among the options. The word "Tesla" refers to a unit of magnetic field intensity, and a field of 3.0 Tesla corresponds to a magnetic field approximately 100,000 times stronger than the geomagnetic field observed around Japan; a field of this strength is produced through the use of superconducting technologies (Photo 2-2). According to our staff, all of the magnetically recorded information on the credit cards we shop with would be erased if we accidentally brought them into this room.

This MRI makes use of the BOLD (blood-oxygen-level dependent) effect caused by the difference in the magnetic properties of oxidized and deoxidized hemoglobin in the bloodstream to determine the local blood flow in the brain. This effect allows for the non-invasive measurement of brain activity (the process known as fMRI). The 3.0-Tesla MRI unit displays a higher signal-to-noise ratio compared to conventional 1.0 or 1.5-Tesla units, in turn enabling high-precision measurements of sensory areas such as the visual cortex (Photo 3). However, caution must be exercised when performing measurement in areas of varying magnetic sensitivity — from tissues to bodily fluids to air. It is known that measurements of brain activity in specific parts of the frontal lobe near the orbital and nasal cavities are difficult due to the difference in the magnetization of body tissues that takes place within a high magnetic field. The researchers of the Biological ICT Group are thus studying ways to remove these effects in order to develop a better method of measuring frontal-lobe activity. They are also applying the elements of this method to measure the sorts of brain activity associated with emotion and thinking (Photo 4) and conducting basic studies on computerizing the methodology to pave the way for applications in communication technology.

The method using the BOLD effect has its limits. Since the metabolic responses that change blood flow occur in millimeter-scale areas that are larger than (micrometer-scale) neurons, a time lag arises between the actual moment of brain activity and the moment this activity is reflected as a change in blood flow, preventing high temporal resolution in mapping. Further, signal changes due to hemoglobin in the blood within the blood vessels can be misidentified as activity in surrounding brain areas. These difficulties have led to the rise of new research themes


Photo 2-1. The fMRI unit, which generates a high magnetic field of 3.0 Tesla


Photo 2-2. The fMRI unit is equipped with an eight-channel phased-array coil to generate a high magnetic field.


Photo 3. A magnetically shielded operation room for the fMRI, from which various experiments are controlled

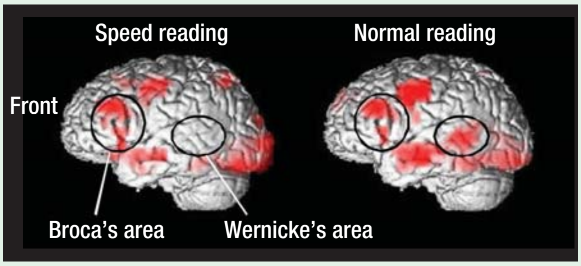


Photo 4. Example of brain activity measurement
(From the SEP. 2004 issue of NICT News, "How the Brain Works in Speed Reading")

for POST-BOLD-fMRI, such as diffusion-weighted fMRI. Few groups are conducting basic research in these areas, and those that are doing so are eliciting a great deal of anticipation for the application of their results to a variety of medical fields.

Toward a Precise Method of Measuring Brain Information

Along with these R&D efforts in fMRI, the Biological ICT Group is also conducting research on MEG (magnetoencephalography) and NIRS (near-infrared spectroscopy). The details of these studies will not be presented here due to limitations of space, but all three instruments have specialized features; by combining the results of the measurements in which each system excels, we will be able to arrive at more precise overall measurements of the brain.

Toward the Future in Info-Communications

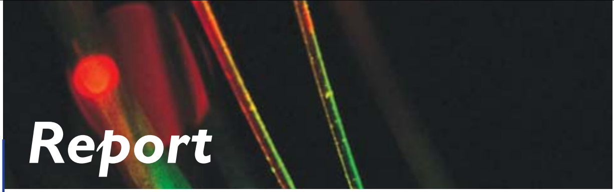
The R&D efforts conducted at KARC include the development of instruments to measure information on the brain—the goal of the Biological ICT Group—as well as basic R&D that spans multiple fields, pursued under joint projects between various groups at KARC. The Biological ICT Group introduced in this issue is pursuing studies on brain information that are expected to lead to new concepts in info-communication. Thus at KARC a multi-faceted approach is taken for a range of research, contributing to the facility's clear role as an important center in the development of future info-communication technologies.

<Terminology>

*1 fMRI: "f" stands for functional, and "MRI" is the acronym for magnetic resonance imaging. This is a method of imaging cross-sections of the human body using nuclear magnetic resonance (NMR) phenomena, mainly associated with the hydrogen atom.

*2 MEG: an acronym for magnetoencephalography, the measurement of brain activity by detection of the extremely weak magnetic signals generated by the electrical activities of the brain using superconducting quantum interference devices (SQUID).

*3 NIRS: Near-infrared spectroscopy is a non-invasive, low-confining method of measuring brain activity that applies near-infrared spectrometry to measure the amount of infrared energy generated through brain activity to determine changes in hemoglobin volume in the brain.



International Symposium on the Bioelectromagnetic Environment — Guidelines for Electromagnetic Wave Safety —

Soichi Watanabe, Research Manager, Electromagnetic Compatibility Group, Applied Electromagnetic Research Center

Recent years have seen significant growth in the types and number of devices using radio waves, from cellular phones to electronic tags. As part of the process of setting standards for safe levels of electromagnetic waves emitted from wireless devices, countries around the world have created guidelines to limit human exposure. Most of these guidelines, including Japan’s, have been drawn up by specialists in the respective countries based on current scientific knowledge and upon guidelines set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), with the recommendation of the World Health Organization (WHO).

With the cooperation of the ICNIRP, NICT held an international symposium on Nov. 8, 2006 in the main hall of Zenkoku Toshi Kaikan in the Chiyoda Ward of Tokyo titled as indicated above. The aim of the symposium was to provide an opportunity for the general public to learn about the efforts made throughout the world—including those underway here at NICT — to limit the adverse health effects of electromagnetic waves, a growing concern in recent years. Top experts in the field from Japan and abroad attended the numerous presentations.

Opening speeches by NICT’s Vice-President, Dr. Matsushima, and the Director-General of the Radio Department of the Telecommunications Bureau of the Ministry of Internal Affairs and Communications, Mr. Kawauchi, were followed by a summary of international guidelines on electromagnetic wave safety, provided by the chairman of the ICNIRP. A panel discussion was then held by members of ICNIRP, WHO, and NICT. In an exceptionally noteworthy presentation, Ms. Kaori Yamane, Vice-President of the Shufuren (Housewives’ Association) delivered “A Proposal to the Government and Specialists from the Perspective of a Common Consumer.” The listeners gained a great deal from the fresh perspective, and afterward both Japanese and foreign participants spoke highly of the presentation.

NICT has always promoted research on electromagnetic wave safety as a theme for environmental issues in electromagnetic radiation (and specifically those related to electromagnetic compatibility, or EMC). We have been especially active in the study of a standard evaluation method to verify compatibility with guidelines limiting electromagnetic exposure based on high-precision technologies to assess electromagnetic radiation exposure, as well as in the development of instruments for experiments to evaluate exposure in medical and biological contexts. In the future, the ways in which we use electromagnetic radiation will become even more complex; accordingly, we plan to continue in our efforts to develop technologies to evaluate exposure, in order to ensure that society will have the tools it needs to respond to this increasing complexity.

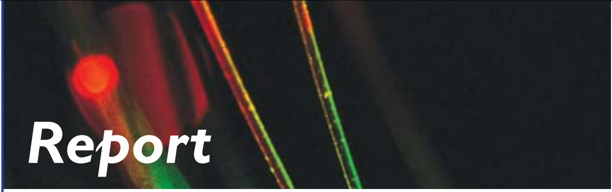
We are deeply grateful to the Electromagnetic Environment Division of the Ministry of Internal Affairs and Communications, to Prof. Masao Taki of the Tokyo Metropolitan University, who is also a member of the ICNIRP (serving as a guest professor at NICT), and to all those who provided support in preparing the symposium.

A scene from the symposium

Panel discussions
Dr. Vecchia (ICNIRP chairman, center)

Oral presentation by Ms. Kaori Yamane, Vice-President of the Shufuren (Housewives’ Association)

International Symposium on the Bioelectromagnetic Environment
— Guidelines for Electromagnetic Wave Safety —
Date: Nov. 8, 2006
Venue: Main hall of Zenkoku Toshi Kaikan (Chiyoda Ward, Tokyo)



Eighth International Conference on Quantum Communication, Measurement, and Computing (QCMC2006)

Masahide Sasaki, Research Manager, Advanced Communications Technology Group, New Generation Network Research Center

The eighth meeting of one of the major international conferences in the quantum info-communication field, the International Conference on Quantum Communication, Measurement and Computing (QCMC), was hosted by NICT (co-hosted by Tamagawa University; co-sponsored by the Ministry of Internal Affairs and Communications of Japan) from November 29 to December 3, 2006 at the International Congress Center Epochal Tsukuba. The conference is held every two years, rotating between host countries, and offers an opportunity for the leading researchers in the field of quantum information to give presentations and to discuss a wide range of themes from basic science to applied technologies. The present conference was attended by 128 Japanese and 150 foreign researchers, who reported on the most recent results of their research in quantum info-communications and quantum computing.

The major European research institutes reported on the rapidly developing single-photon control technologies and quantum cryptographic systems of recent years, and Japan's NEC and NTT presented the results of R&D on the latest metro-quantum-cryptographic system, an area of research contracted by NICT. Additionally, following a series of reports in 2006 by the Centre National de la Recherche Scientifique (National Center for Scientific Research), the Niels Bohr Institute (Denmark), and NICT confirming validation of the technology for simultaneous control of 5 or 6 photons, the latest results of these validation experiments were given by the respective parties, forming a central theme of the conference. These presentations strongly indicated that the field has passed the stage of single-photon control, entering a new phase of research in macroscopic quantum control.

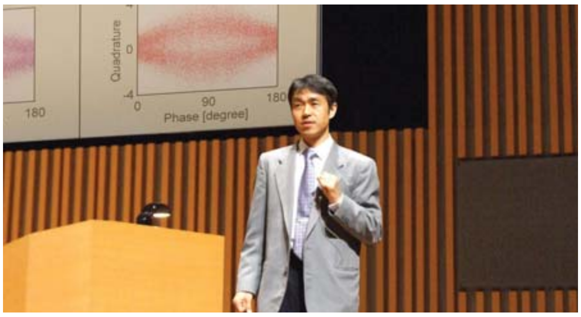
Numerous reports were also given on the achievements of collaborative projects among industry, academia, and the government that have been promoted by the Ministry of Internal Affairs and Communications and NICT since 2001. Many of the researchers attending the meeting seemed keenly interested in these research results and specifically in NICT's comprehensive research resources, and we received numerous requests for visits to our facilities and for joint research. We now have plans to promote a number of international collaborative projects among industry, academia, and government: field validation experiments of quantum cryptographic systems using the JGN II testbed network, quantum signal processing research, and projects in space quantum communications, to name a few. These kinds of projects are now becoming possible through the R&D resources of NICT, combined with the collected advanced technologies of the major institutions in the field of quantum information — including NIST and Northwestern University in the USA, the Max Planck Institute and Erlangen University of Germany, the European Space Agency, and the University of Science & Technology of China.

It is of significant note that NICT was able to host the QCMC at such an important turning point in quantum info-communication research, an area in which we are about to see an enormous leap forward, and I'm sure that all of us at NICT are particularly cognizant of the obligations we have in promoting innovation of the info-communication networks that will serve society in the latter half of the 21st century.

I would like to thank all of the organizations and individuals who helped make this conference a success.

Opening speech by the President of NICT, Dr. Nagao

Main assembly hall

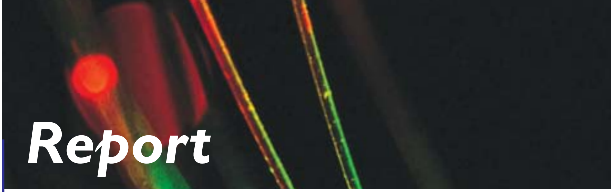


Invited lecturers (Dr. Masahide Sasaki, Research Manager in NICT)

Exhibition of instruments
(Research contracted by NICT: Quantum Cryptographic System)

Scene from the poster session

Eighth International Conference on Quantum Communication, Measurement, and Computing (QCMC2006)
Date: Nov. 29–Dec. 3, 2006
Venue: International Congress Center Epochal Tsukuba (Ibaraki Prefecture)



Bringing our Research Achievements to You

Fumitake Sawada, Expert, Intellectual Property Management Group, Research Promotion Department

One of the key factors in successfully disseminating the achievements of our research efforts widely among the general public is to market a technological product that costs less than competing products. However, this doesn't mean that we should offer our technology for free to businesses—such distribution would hardly qualify as successful dissemination. We believe that the conventional method remains the best, in which a useful technology developed as a result of our research is licensed to private companies at a fair price, so that it can be commercialized and marketed, and the technology becomes disseminated throughout society as a result. One index representing the degree of such dissemination may be found simply in the number of products sold. In other words, if the results of NICT's research (patents, etc.) are licensed to private companies, the extent of their dissemination may be estimated by examining the total number of products sold. Immediately after NICT had become an independent administrative agency, only several units of a single product had been sold, at a price tag of several tens of millions of yen per unit. Today we have products that are marketed at several tens of thousands of yen, and some of them have even sold in the millions of units. Clearly, the results of our research are becoming more accessible to the public.

On November 20, I happened to find a magazine with a DVD giveaway at the checkout counter at a convenience store in Tokyo (Fig. 1). Were any of you aware that our technology is used in this DVD? This DVD contains encryption software developed by ChaosWare Inc., a venture company with its origins at NICT. The software can be used for free, since the cost of the software is paid for by the advertiser. Thus, advanced encryption software is now available for free to the general user (Fig. 2). By providing this sort of cost-free software, we hope to disseminate our encryption technology to such general users. Note that while this DVD is free of charge, the license fee to NICT is paid from advertising revenues.

Coming across this DVD and similar incidents make us realize that our recent achievements are being successfully disseminated among the public, and these occasions are a real pleasure for the members of our group whose job is to support the research activities of NICT. We hope that in the future NICT's achievements will become even more widespread and come to form a common feature of our daily lives.

Fig. 1 DVD at the checkout counter of a convenience store

Fig. 2 Page for encryption software in the DVD magazine

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