The University of Electro-Communications

UEC e-Bulletin

Updates on research, innovation, and events at UEC:
Unique and Exciting Campus in Tokyo

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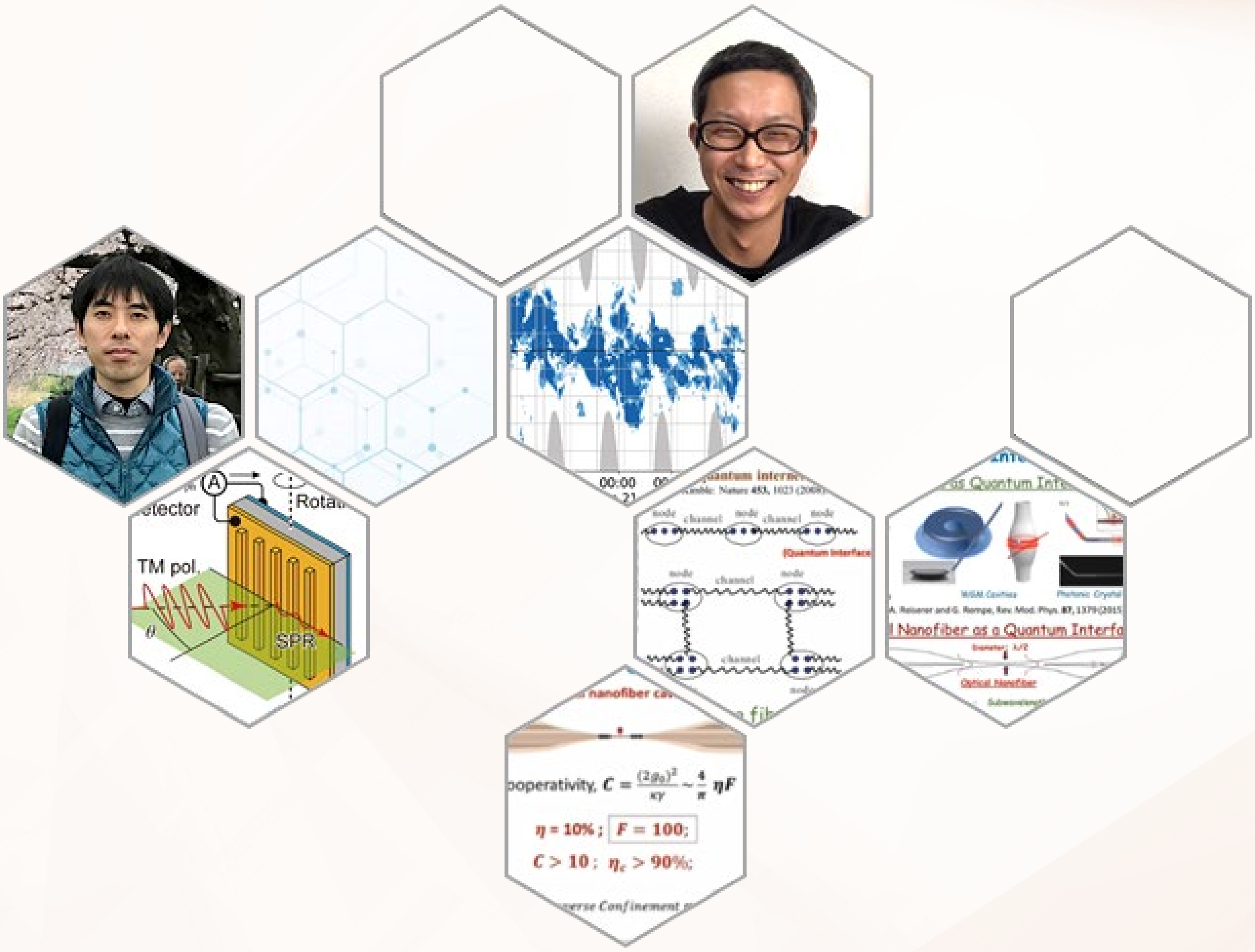


The University of Electro-Communications 1-5-1 Chofugaoka, Chofu, Tokyo 182-8585

Research Highlights

Researcher Video Profiles

Musical acoustics

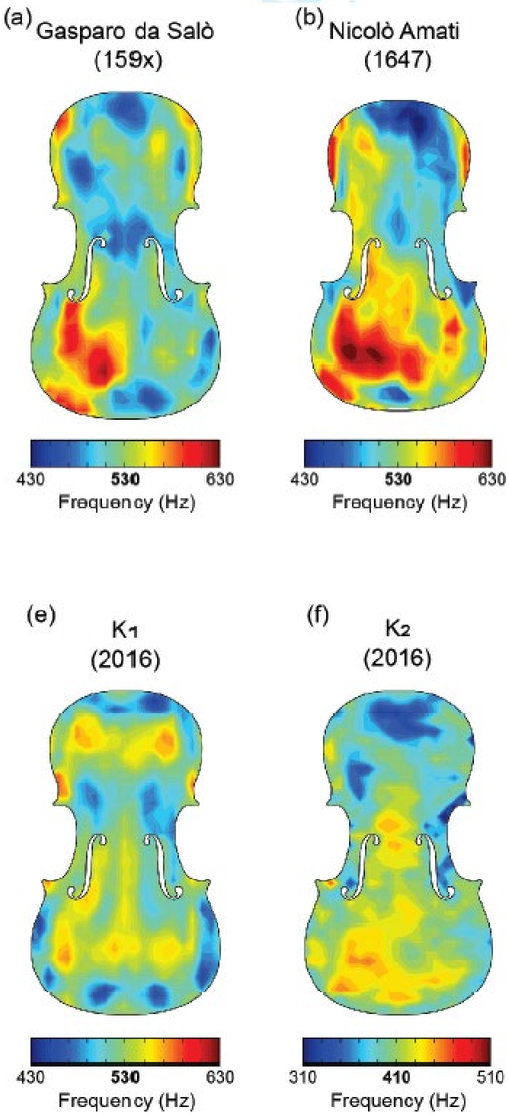
Tapping into the sound of violins

Violins made by instrument makers in northern Italy up to the early 19th century are world-famous for their sound. Violins from that epoch have been thoroughly analysed by modern methods in order to understand — and replicate — their superior acoustic qualities. Specifically, the shapes and sizes of old Italian violins have been studied in detail, which helps to comprehend, to some extent, the original design of these instruments. However, because not all violin-making technical know-how was consistently passed on to apprentices, it is not entirely clear today how exactly the renowned designs of the 'old' Italian violin builders were conceived. Now, Eriko Aiba from the University of Electro-Communications and colleagues report that frequency maps derived from the sounds obtained by tapping a violin's top plate are valuable acoustic characteristics, and suggest that such tapping may have been a key technique used by the famous Italian violin makers from centuries ago.

The scientists compared violins from three categories: two old Italian instruments (a violin made in the 1590s by Gasparo da Salò from Brescia and a violin made in 1647 by Nicolò Amati from Cremona), two post-19th-century Italian instruments (one made in 1916 in the Mantua region and one made in 2016 in the Cremona region), and two instruments made by a Japanese instrument builder in 2016. The latter two were manufactured making use of the tapping technique with the aim of reproducing the characteristics of old violins. Each of the violin tops was placed on a soft cushion. A laser grid pattern of lines spaced 1 cm apart was projected onto the top; tapping was done (either by a finger or by a metal rod) at about 500 grid points for each top. The sounds produced by tapping were recorded by microphones installed near the violin top.

The researchers then calculated the so-called centroid frequency for each of the grid points on the violin tops; the centroid frequency can be thought of as a representative value of a frequency spectrum. Plotting these frequencies as 'heat maps' then made it possible to compare the acoustics of the 3 violin pairs. Within each of the three categories, and especially for the two pairs of Italian violins, the frequency maps were strikingly similar. The two old Italian violins display a high centroid frequency around the chin rest area, which can be attributed to repeated coating with varnish, whereas the later Italian violins have a generally asymmetric frequency distribution. The results also showed that the contemporary Japanese violins, the top thickness of which was adjusted during construction by analysing tapping sounds, had frequency distributions similar to those of the old Italian violins.

Aiba and colleagues conclude that their results "support the possibility that tapping was used in the violin manufacturing process in northern Italy by the early 19th century when measuring instruments had poor precision, although further evidence of old violin samples is needed to substantiate this hypothesis".



[Fig.3 from the paper]

Centroid frequency distributions of the 3 pairs of investigated violins.

Katuhiro Maki, Eriko Aiba and Satoshi Obata, Characterizing violin top plate using sounds generated by local taps, *Acoustical Science and Technology*.

URL: https://www.jstage.jst.go.jp/article/ast/43/2/43_E2124/_article/-char/en

DOI: https://doi.org/10.1250/ast.43.87

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Gas sensing

Spectroscopic gas detection

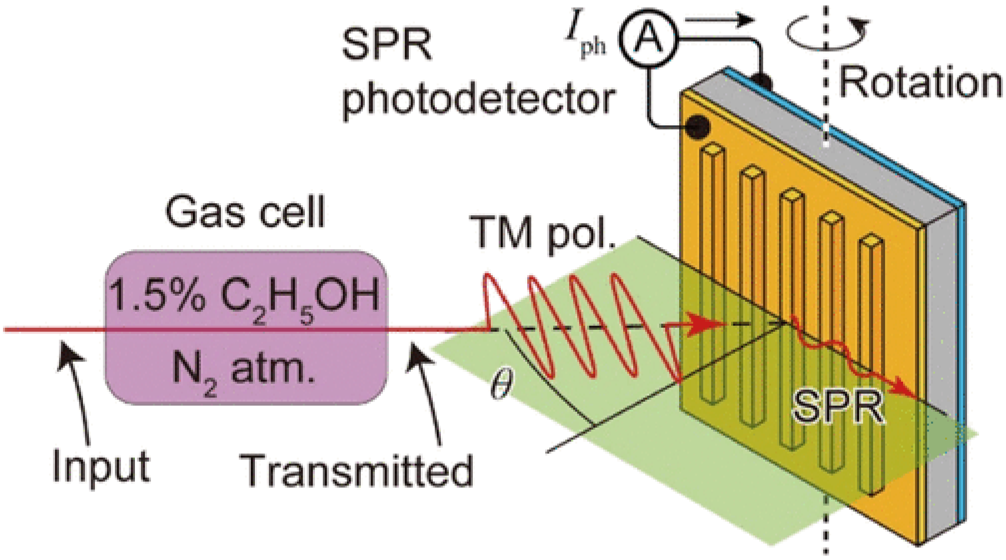
Small gas sensors are used in many settings for detecting specific gases — for example, recognizing explosive or smelly gases — or for analysing the composition of atmospheric gas. Most gas-sensing methods require a separate sensor for every type of gas. Yet, in light of on-going efforts to miniaturize such devices, a single detector that can sense different gases is highly desirable. One approach towards 'unified' sensing relies on spectroscopy: by analysing the absorption frequency spectrum of light passing through a gas mixture, the components of the mixture can in principle be identified. Now, Tetsuo Kan from the University of Electro-Communications and colleagues report the successful application of spectroscopic sensing in a miniaturized setup. The principle behind the sensor is so-called reconstructive spectroscopy, in which a spectrum is not directly measured, but reconstructed by converting other measured quantities. The scientists' spectrometer reaches a wavelength resolution of 20 nm, and, by way of test, was able to detect ethanol gas.

The difficulty with miniaturizing a normal spectroscopic device lies in the need for a long optical path length in order to disperse light into its different wavelengths. Reconstructive spectrometers overcome this issue by letting light interact with a photonic material — a structure with dispersive properties. The photonic material is located close to the optical detector, enabling compact construction. Kan and colleagues developed a spectrometer with a gold grating as the photonic material. Upon irradiation with light (having passed through the gas mixture being examined), electrons in the grating start to oscillate, a process called surface plasmon resonance. The grating is made to rotate, and because of the irradiation-induced surface plasmon resonance, an electrical current develops, which can be measured and converted into a frequency spectrum. (The current depends on both the angle of incidence and the wavelength.)

For the light source, the researchers used near-infrared light — electromagnetic radiation with wavelengths in the range 800 nm – 2500 nm. First, they tested how their device performed spectroscopically; that is, how well it could reconstruct spectra, and with what resolution. The measurements showed that wavelength peaks spaced 20 nm apart could still be clearly distinguished.

Then, the scientists examined how well their reconstructive spectrometer can detect a gas. They choose to perform a test with ethanol gas, which is known to absorb near-infrared light with a wavelength of 1392 nm. The drop in transmittance at that wavelength was clearly seen in the reconstructed spectrum.

Kan and colleagues conclude that their reconstructive spectrometer has the capacity for gas measurement. Although there is room for further improvement — for example, in the current experiments, a combination of single-wavelength sources was used, whereas a continuous-wavelength source is preferable — the researchers are confident that the "advancement of the proposed method will result in the development of a new micro-sized integrated spectrometer that will provide rich information on our environment".



[Graphical Abstract from the paper]

Schematic of the working principle of a reconstructive spectrometer for gas sensing.

Yosuke Yamamoto, Masaaki Oshita, Shiro Saito, and Tetsuo Kan, Near-Infrared Spectroscopic Gas Detection Using a Surface Plasmon Resonance Photodetector with 20 nm Resolution, *ACS Appl. Nano Mater.* **4**, 13405–13412 (2021).

URL: https://pubs.acs.org/doi/10.1021/acsanm.1c02925
DOI: 10.1021/acsanm.1c02925

Atmospheric science

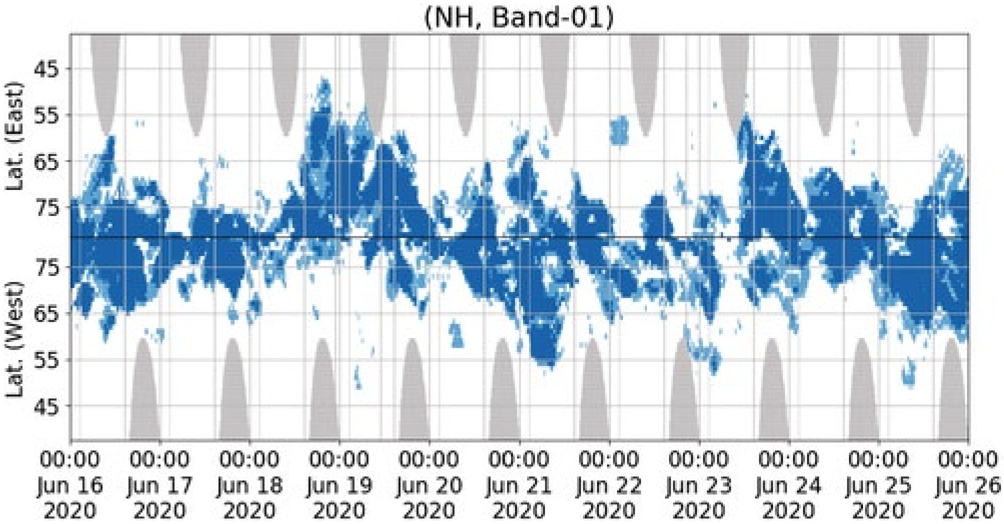
Night cloud watching from space

Polar mesospheric clouds (PMCs), also called noctilucent clouds, occur in the upper layer of the Earth's atmosphere, the so-called mesosphere, at altitudes between 76 km and 85 km. They consist of ice water particles and can typically be observed at high latitudes at night when the lower part of the atmosphere is already in the Earth's shadow but the upper part is still in the sunlight. Since 2007, PMCs are being studied from space by means of the NASA-operated AIM (Aeronomy of Ice in the Mesosphere) satellite, a low-Earth-orbit satellite launched with the aim to better understand why PMCs form, and what the origin of their variations is. Now, Takuo Tsuda from the University of Electro-Communications and colleagues have looked into the possibility of using data from a geostationary-Earth-orbit (GEO) satellite to detect PMCs. They developed a two-step processing scheme for data recorded by the GEO Himawari-8 satellite operated by the Japan Meteorological agency, and found that results generated in this way can be used for scientific PMC research.

GEO satellites are in an orbit with the same rotational speed as the Earth, so that they are always located above the same spot on the Earth's surface. The Himawari-8 satellite is located at 140.7° East so that it covers the Asia-Pacific region, and has instruments on board that can detect visible and infrared light. Its spectral images have a spatial resolution of about 1 km, and a relatively high time resolution of 10 minutes — the latter is a particular advantage of Himawari-8 in the context of studying PMCs.

Tsuda and colleagues analysed spectral signals for various frequency bands, and first calculated average intensity values for a 3D point grid of the part of the atmosphere captured by the Himawari-8 satellite; a point has coordinates latitude, longitude and altitude. To decide whether, at a given time, a point is 'occupied' by a PMC or not, they compared the intensity to the value for a dark (i.e. cloudless) spot. If the intensity does not lie above a certain threshold, it is assumed that there is no PMC there. In a second, refining step, the scientists corrected the selection threshold for Rayleigh scattering effects (stemming from electromagnetic radiation being scattered by particles that are much smaller in size than the radiation's wavelength), to ascertain the inclusion of weaker PMC signals.

The researchers studied PMC signal maps obtained in this way with data generated since 2015. They were not only able to recover the typical day-to-day and year-to-year variations in PMC formation, but they also noted many shorter time scale structures. These could be detected thanks to the 10-minute time resolution of the Himawari-8 satellite, and may be related to atmospheric tidal waves. Tsuda and colleagues also performed a thorough validation of their data processing scheme by comparing their results to the data recorded by the AIM satellite, and found that there is excellent consistency between the two different PMC datasets. The scientists concluded that "the current data product would be of benefit for research on various PMC science in the longer time scales" and expect that in the future, further data analysis will enable to "produce newer PMC science in the shorter time scale (with the 10-min) resolution".



[Fig. 4 from the paper]

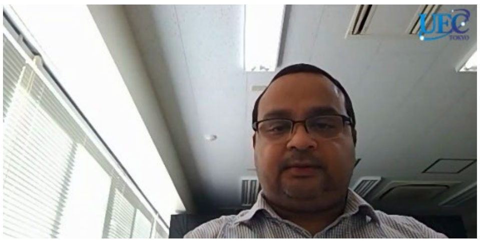
Exemplary plot of the day-to-day variation in detected PMCs by analysing data from the Himawari-8 satellite. Dark blue indicates PMCs detected in the first processing step, light blue indicates PMCs detected in the second, refining processing step taking Rayleigh scattering effects into account.

T. T. Tsuda,Y. Hozumi,K. Kawaura,K. Tatsuzawa,Y. Ando,K. Hosokawa,H. Suzuki,K. T. Murata,T. Nakamura,J. Yue,K. Nielsen, Detection of Polar Mesospheric Clouds Utilizing Himawari-8/AHI Full-Disk Images, *Earth and Space Science* **9**, e2021EA002076 (2022)

URL: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2021EA002076
DOI: 10.1029/2021EA002076

Developing a single atom quantum interface on a tapered optical fiber

Kali Prasanna Nayak
Associate Professor, Department of Engineering Science
Developing a single atom quantum interface on a tapered optical fiber



In this video, Kali Prasanna Nayak describes his research on developing a single atom quantum interface on a tapered optical fiber, starting with an overview of the concept of quantum interfaces and recent developments in quantum computers based on trapped ions, trapped neutral atoms or superconducting qubits. Nayak says that the "next challenge will be how to connect these quantum nodes over a network where single photons will be the information careers; the so-called quantum internet."

Notably, single photons can be efficient carriers of quantum information because they can move at the speed of light and do not easily interact with the surrounding medium. However, these same properties lead to difficulties in isolating and controlling single photons. One way to resolve this problem is the development of quantum interface platforms where single photons can be controlled/manipulated using an ensemble of atoms.

"If this could be done at the single atom level then one can use the quantum properties of the single atom to further enhance the quantum functionality of such a quantum node," says Nayak.

But the question is why is it so difficult to realize a single atom quantum interface?

One way of overcoming this problem can be devised by considering the efficiency with which a photon interacts with a single atom. To quantify this, the parameter known as the 'single atom cooperativity' is defined that is the ratio of single atom absorption cross-section to the photonic mode area.

"This means that we have to strongly confine the single atoms and photons to subwavelength dimensions to realize efficient interaction," explains Nayak. "This is about transverse confinement. Another way is to confine a single atom inside a high finesse optical resonator, where the interaction will be further enhanced by the number of photon round-trips inside the cavity i.e. the finesse of the cavity. This is called longitudinal confinement."

These ideas are being pursued worldwide to develop a quantum interface using micro-cavities and nanostructures. "In my group, we are trying to develop a quantum interface on an optical nanofiber i.e. a tapered optical fiber with subwavelength diameter waist," says Nayak. "The diameter of the nanofiber is almost half of wavelength, with the primary advantage of such a technique is that the fiber guided mode can be strongly confined in the transverse direction to subwavelength dimensions while interacting with the surrounding medium in the evanescent region.

Apart from the transverse confinement, one can also introduce an in-line cavity on the nanofiber to further enhance the atom-photon interactions. After all this is a fiber in-line technology easily integrable to fiber networks."

Nayak also describes the advantage of transverse confinement, where he compares a free-space cavity with a nanofiber cavity, stressing that to realize a cooperativity of ten in free-space cavities requires a finesse of half a million. Similar cooperativities can be realized on a nanofiber cavity with a moderate finesse of hundred to two hundred. This is because of the strong transverse confinement in nanofiber cavity. In free-space cavities, the effective mode radius is order of tens of microns whereas that for a nanofiber cavity is only half a micron; this is the key advantage.

Cavities are fabricated in thin fibers using femtosecond laser fabrication techniques to produce photonic crystal cavities on nanofibers.

The next question is how to trap a single atom on such a nanofiber cavity? "We use this kind of tightly focused optical dipole trap, the so-called single atom tweezer, to trap individual atoms on the nanofiber cavity," says Nayak. "The key point of such a tightly focused trap is that the trap volume is so small that it can trap only one atom at a time. If two atoms enter the trap, they will collide with each other and will be lost from the trap. It is known as the collisional blockade mechanism."

Nayak and his group have conducted wide variety of experiments based on this approach and have produced a nanofiber cavity and an optical tweezer beam tightly focused on the nanofiber. "We load atoms into the nanofiber trap from a laser-cooled atom cloud formed by a standard magneto-optical trap (MOT) and monitor the photon counts through the fiber guided modes. We observed the photon count rates as a function of time and saw clear single-step-like signals. This indicates that single atoms are trapped and interfaced to the nanofiber. The fluorescence from the trapped single atom is coupled to the nanofiber guided modes and that results in such step-like fluorescence signals."

Nayak and his group confirmed these results by measuring the photon correlations, where anti-bunching of fluorescence photons clarified that these signals were from individual single atoms. "We have also measured the trap lifetime to be around 50 ms, and from photon counts we estimated a cooperativity of 5.4 and channeling efficiency as high as 85%," says Nayak. "This means that almost 85% of the atomic emission is coupled into the fiber guided modes. That's a very efficient single atom quantum interface. Such interfaces offer new possibilities for fiber in-line quantum nodes and single photon manipulation."

Research Keywords: Quantum Optics, Nanophotonics, Nanofiber optics, Laser cooling and trapping, Control and manipulation of single atoms and single photons

Reference and further information

Reference: K. P. Nayak, J. Wang, and J. Keloth, Real-time observation of single atoms trapped and interfaced to a nanofiber cavity, Phys. Rev. Lett. 123, 213602 (2019).

DOI: https://doi.org/10.1103/PhysRevLett.123.213602

Lab Website: https://sites.google.com/view/kali-prasanna-nayak-uec/home?authuser=0

The University of Electro-Communications (UEC) in Tokyo

is a small, luminous university at the forefront of pure and applied sciences, engineering, and technology research. Its roots go back to the Technical Institute for Wireless Commutations, which was established in 1918 by the Wireless Association to train so-called wireless engineers in maritime communications in response to the Titanic disaster in 1912. In 1949, the UEC was established as a national university by the Japanese Ministry of Education, and moved in 1957 from Meguro to its current Chofu campus Tokyo.

With approximately 4,000 students and 350 faculty, UEC is regarded as a small university, but with particular expertise in wireless communications, laser science, robotics, informatics, and material science, to name just a few areas of research.

The UEC was selected for the Ministry of Education, Culture, Sports, Science and Technology (MEXT) Program for Promoting the Enhancement of Research Universities as a result of its strengths in three main areas: optics and photonics research, where we are number one for the number of joint publications with foreign researchers; wireless communications, which reflects our roots; and materials-based research, particularly on fuel cells.

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The University of Electro-Communications
1-5-1 Chofugaoka, Chofu, Tokyo 182-8585
E- mail : kokusai-k@office.uec.ac.jp
Website: http://www.uec.ac.jp/eng/