（別紙様式５）

変革を駆動する先端物理・数学プログラム（FoPM）
国外連携機関長期研修　報告書

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受入先	沖電気工業株式会社
日程	西暦 2022 年　01 月　01 日　～　西暦 2022 年　03 月　31 日

This is a report on the Paid Internship Program organized by MEXT. MEXT introduced the program right this year. I participated in the program as one of the first students at the University of Tokyo.

<Research and Result>

OKI is developing new sensing equipment using optical fiber. By vibrating part of the fiber and observing the backscattered light in the fiber, it is possible to detect when and where the fiber was vibrated. These sensing techniques are expected ways to monitor social infrastructure. One of them is Phase-sensitive optical time domain reflectometry (Φ-OTDR).

Φ-OTDR can detect distributed vibration along with the whole optical fiber with high sensitivity, by observing Rayleigh Back Scattering (RBS) light in sensing fiber. The following is the vibration detection principle of Φ-OTDR.

The incident light field is expressed as $E = E_0 e^{-i\omega t}$ where ω is the angular frequency. The light is injected into the optical fiber and part of it returns to the end face of the fiber due to RBS. The return signal is the superposition of a series of N small RBS centers within the spatial resolution. Therefore the return signal from around section A can be described as $E_0 e^{-i\omega t} \sum_N r_n e^{i\phi_n} \sim A e^{i(\phi_A - \omega t)}$ where r_n is amplitude and ϕ_n is phase of the n-th scattering light field. When external vibrations with the frequency $\theta(t)$ are applied between section A and B, the return signal from around section B will be $e^{i\theta(t)} E_0 e^{-i\omega t} \sum_M r_m e^{i\phi_m} \sim B e^{i(\phi_B + \theta(t) - i\omega t)}$. Hence, the time derivative of the difference in phase between the backscattering light from A and B is the vibration frequency.

Before this internship program, I had no knowledge about this sensing technique. I had developed lasers exclusively at visible to ultraviolet wavelengths, and never handled the laser whose wavelength is in the communication wavelength band. Each optical element was new to me in the vibration measuring system I saw at OKI's Lab. On the other hand, some measurement procedures and principles were familiar to me. During this internship program, I operated the equipment that OKI is developing. While understanding the design of the system, I considered how to improve the accuracy of the measurement.

In Φ-OTDR, measured optical electric field is a superposition of the RBS and noise. This means that the measured phase can differ from that of the ideal RBS. The deviation from the ideal phase depends on the magnitude of the noise relative to the RBS light power. I proposed several methods to reduce the magnitude of noise, which determines the accuracy of the measurement, and demonstrated whether the noise could actually be reduced. I revealed that one of them could reduce the noise under certain conditions better than the method currently used in OKI. As well as advantages, disadvantages also exist. There should be the best parameters for more sensitive measurement. I summarized and presented the results at the Innovation Promotion Center.

<Experience at the Innovation Promotion Center of OKI>

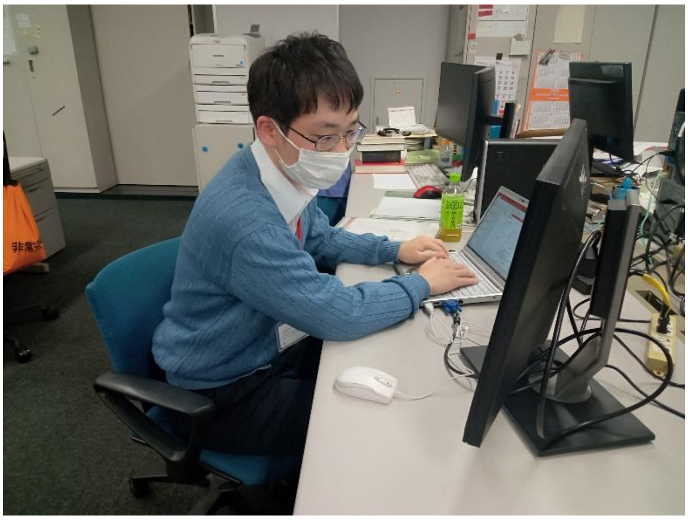
I had no part-time work experience. I naturally had no experience of working in a company. I planned to work in a company after graduation from the Ph.D. program, but I did not know how companies manufactured their products. Under the COVID-19 crisis, it is difficult for me to go outside the University of Tokyo. However, I wanted to participate in an internship at least once during my Ph.D. study. At that time, I received a mail that MEXT had launched a new internship program.

I was the first internship student in this program at the University of Tokyo. Also, this was the first for MEXT, the University of Tokyo, and OKI. When I introduced myself in front of OKI researchers, I was very nervous, but they were kind to me. This was my first step as a member of society.

At OKI, I was given one PC and one mission, which was described in Research and Result. The researchers gave me a series of lectures and showed me the undergoing experiments and the data obtained. After a few days of thinking, I proposed several primitive but seemingly effective methods to solve the problem. They readily accepted my proposal. I was free to get to work. I set up a python environment on a borrowed PC, looked at some data I had taken before, and thought about how to put the proposed methods into practice.

When I was struggling, the researchers consulted with me. When I explained my results, they listened attentively and gave me useful advice. I was working as a fellow researcher! I could have confidence in myself.

During my job, I heard the researcher next to me have sold a device he had developed as a product. He told me about the attraction of R&D in company. For instance, exchanging ideas directly with people who might buy my product and redesigning a device I have developed to sell as a product are things I may not find in my research at the university. I was strongly interested in the research at a company and got a good experience to imagine what my future would look like.



Working at my desk.