Guest Forum

Series of Lectures by Screening Committees of the Second Masao Horiba Awards

The Way to Engineering Spectroscopy

– Tracing the History of Instrument Development and Passing It on to the Future –

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Since 1950, I have adhered to the development and research of spectroscopic instruments that started as industry-university joint research, and, with regard to the spectroscopic measurement systems from ultraviolet to far-infrared, continued to study various elemental technologies including light sources, spectroscopic units, photo-detection processes, etc., as well as their integration by means of systematization and computerization technologies. I would like to introduce you to the stream of Engineering Spectroscopy, which has been absorbing the achievement of evolving peripheral technologies and organizing the application - equipment correlations as practical technologies, and there include some talk about my experiences.

Introduction

Having been enchanted by optics, I have pursued the study of spectroscopic-measurement-based instrument development. In instrument development, normally, you have to draw up a plan and ask back-street factories for its production. Therefore, three to five years will pass very quickly. Sometimes, you cannot escape from a situation in which you are completely unable to write your paper until an instrument is finished. I have been involved in a job that academic people most likely hate, but I have no regrets about what I have done because it was a labor of love for me. I retired from Osaka Electro-Communication University 4 years ago, and I am now enjoying my life as a consultant where I spend time talking to engineers from industry.

I remember, when I was young, Professor Yoshinaga, my great teacher, said to me, "Spectroscopy has to head for an area of application for the future", to which I interjected, "I will be going for more practical low-end spectroscopy." Having the same idea even now, I am exploring various ways of making use of spectroscopic technology on the idea that it could be useful in many fields, i.e. for not only industrial and medical worksites but also widely across the homeland security field including criminal identification, etc.

While explaining to you now about what I experienced in the past 50 years, I would like to pursue the topic with a view of "looking to the future by looking back at the past", and tell you about how many scientific measurement engineers contributed to the industry with their technical expertise, and how well they digested the peripheral technologies to deal with the development of spectroscopic instruments.

Past 50 Years Process of Development and Research into Spectroscopic Instruments

Days when you were not able to think of Precision Instruments without thinking of "Cameras", "Watches" and "Sewing Machines"

There was a time -- during the war -- when both 4th and 5th grades students of the old educational system of middle schools had to graduate at the same time. In that year, I entered the Department of Mechanical Engineering (precision instrument major) at Osaka Technical College (under the old educational system). Since I had been a great lover of aircrafts since I was a boy, I wanted to become a Navy engineer specialized in aeronautic instruments and applied for a place as a dispatched technical student, but the war was over before the entrance examination. Fortunately, as part of the postwar industrial recovery policy, precision instrument industrial promotion measures, following the example of Switzerland, were adopted to make the most of Japanese manual dexterity as added-value. Those days, you were not able to think of the precision instrument without thinking of cameras, watches, and sewing machines. I was interested in watches as well, because I had experience with watch repairs by means of my after-school job and I liked fine mechanical assemblies. However, due to the mysteriousness contained in a camera lens and the variety in mechanical assemblies, as well as the humane aspects of an optical device, which are directly liked to art to mention landscape photography and portrait photography, finally, I decided to join the Laboratory of Professor Tsuneo Nakamura (later a professor at Hokkaido University) who specialized in optical instruments, and I was engaged in study for my graduation thesis. Watches and cameras have their specialty of being a precision instrument used close at hand by the public. In the case of a camera in particular, since it is a precision instrument used close to someone's face where human sensors gather, manufactures designed it with attention to even the smell of camera-body's leather upholstery. While that optical laboratory was quite interesting, the theme of my graduation thesis was a rather unspectacular subject referred to as "Lens's Antireflective Coating". A lens surface causes a reflection loss of 4%. In the case of binoculars and similar, since they use multiple lenses, the volume of light reaching the eyes is reduced to half or less. The binocular was one of the Navy's important weapons used to search for enemy warships appearing on the horizon, and German binoculars had such an antireflective coating applied. The vapor deposition technology to apply the antireflective coating to lenses was one of the latest high technologies at that time.

I decided to take an entrance examination at Osaka University, following the recommendation of my great teacher, Professor Nakamura, who said, "If you intend to make a lifelong commitment to optics, why don't you join the Laboratory of Professor Hiroshi Yoshinaga at the Precision Engineering Department of Osaka University?" I am almost certain that my future was decided at that point in time.

Spectroscopic Instruments Imported in the Postwar Recovery Period

In the Laboratory of Professor Yoshinaga of Osaka University, it seems there was an expectation that I would deal with the study of optical thin films, perhaps because of my previously mentioned experiences. However, since I was absorbed in amateur electronics including do-it-yourself TV assembly, etc., I thought it would be interesting to combine optics and electronics, and formulate them as a system, so I selected to study photoelectric spectrophotometry. It was partly because Japan started importing various automated spectroscopic instruments compatible with sources from ultraviolet to infrared from the U.S.A around 1950, and I was impressed with their design fineness and the skill of their mechanical design. In the U.S.A., those automated instruments were already used for field analyses during the war.

Those days, the spectroscopic instruments locally available in Japan were manufactured in quite a simple way by combining slits and prisms with a photographic plate. Since the most important techniques in physics experiments were glass working and photographic techniques in those days, university seniors eagerly tried to hammer into us the photographic techniques in particular. With regard to ways of distinguishing the two sides of a photographic plate, they said, "Lick it with your tongue." But, now that I think back about it, it was a rather easygoing time. Figure 1 shows a photograph of myself when I was working for the university graduation thesis (in 1950). It is one of the pictures taken when I was doing an experiment with a spectrograph made by Shimadzu Corporation that we got from the authorities, which used to be used for military research by the Army during wartime.

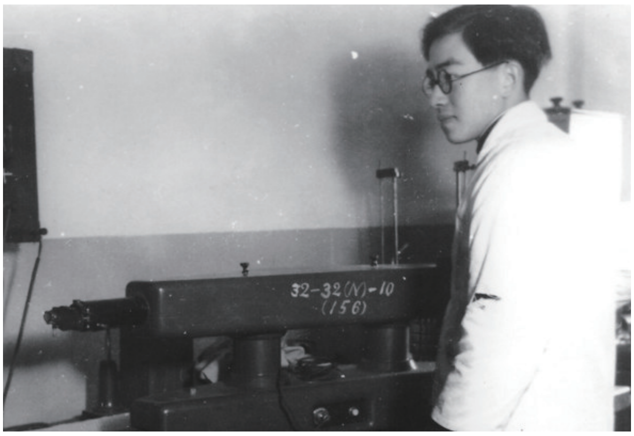

Figure 1 Author Working on his University Graduation Thesis (1950)

Various spectroscopic instruments, such as the ultraviolet - visible spectrophotometer Beckman DU (Figure 2), the ARL Quantometer (photoelectric emission spectrometer), Hardy's automatic-recording visible spectrophotometer from GE, and so forth were imported in the postwar recovery period. They were quite unique spectroscopic instruments equipped with photocells and automatic control systems. The Beckman DU was a Littrow's type device using a 30-degree half-prism to save on the consumption of the raw crystal quartz, yet had the same dispersive effect as a 60-degree prism because of a rear mirror. Nearly 10,000 units were sold in all around the world. The Hardy's (MIT) visible spectrophotometer from GE was just an amazing device for me, who had been dealing with glass working and photography skills only.

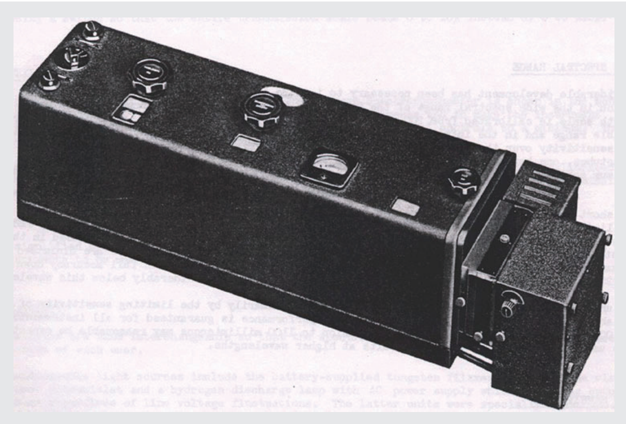

Figure 2 Beckman DU
The company name of Beckman was changed to Beckman Coulter in 1998. DU is the registered trade name of Beckman Coulter, Inc.

Figure 3 shows the optical system. This is a smart double monochromator having a single swing slit with a mirror for the middle slit. It employs a method by which it removes the polarized element of ordinary rays by Rochon prism No.1[*1], divides them into bi-directionally polarized elements using a Wollaston prism[*2], and guides them to a continuously rotating Rochon prism No.2, and then alternately applies them to a sample within the integrating sphere for flicker photometry.

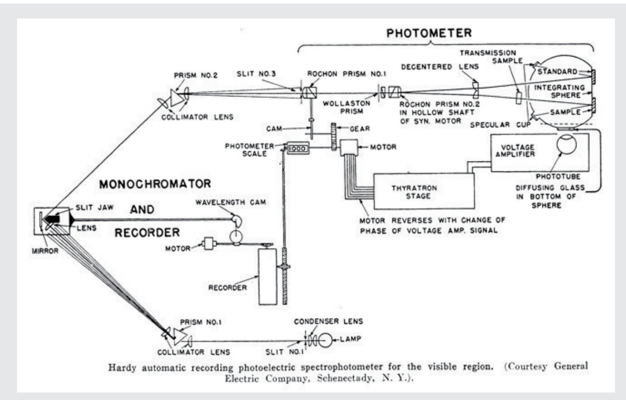

Figure 3 Hardy's Self-recording Visible Spectrophotometer from GE

This idea was first introduced in 1929, and its product was marketed in 1938. If the flicker-photometry output levels are different, feedback information to that effect makes the motor rotate by means of a thyratron until achieving a zero-balance, by controlling the rotation angle of the Rochon prism No.1. In an era when automatic control technology was not organized yet as a system, such a device that makes the most of servo-control technology based on a zero-balance method had been already realized. Those days, it was such an outstanding product that it made us think that it was almost impossible to catch up with U.S. technology.

Then, the import of an infrared spectroscopic instrument followed, but we had nothing to compete with such a product in Japan. While we imported various products like Baird, PerkinElmer, Beckman, etc., they were all different in their optical systems and their automatic-recording methods of optical intensity ratios. In an era when all companies in Japan were trying desperately to make a dead copy of foreign goods, those Western engineers who adhered to their original ways without imitation looked dazzling. I feel that we caught a glimpse of differences in culture in their skill to appeal features like the ease of use at the expense of precision to some extent.

Every time such instruments were introduced into national institutes, they planned a facility tour, in which Japanese manufacturers also participated. While the Japan Society of Applied Physics has been holding a "Spectroscopy Workshop" every year since 1950 and before the Japan Society for Analytical Chemistry was established, it tells you that, in that era, optics and spectroscopy were centerpieces in the field of applied physics.

*1: Polarization prism invented by Rochon, in which an ordinary ray goes straight.

*2: Polarization prism invented by Wallaston, in which the polarized rays of ordinary rays and extraordinary rays are refracted in two opposite directions, respectively.

Joint Development of Photoelectric Emission Spectrophotometers with Shimadzu Corporation

During the postwar era, joint research was mostly done on an individual basis by university professors. While the same applies to present times, I believe that the individual relations of trust between key persons have a significant effect on the success of industry-university joint research.

The nationalization of the Quantometer invented by ARL, of the U.S.A. in 1944 was initiated via the cooperation with Shimadzu Corporation using a 1951 mining and industrial tests and research subsidy from the Ministry of International Trade and Industry, and I participated in the project as a special intern from the old educational system graduate school, and mainly took charge of mechanical design including the drawing of sheet metal design, within the school-side group. This was a research project brought by Dr. Yoshimi Tachibana from Shimadzu Corporation (later, Executive Managing Director). Dr. Tachibana was by a year senior to Professor Yoshinaga at the Kimura Laboratory in the Faculty of Science of Kyoto University. While it is normal for any developing country to start their manufacturing with the copying of imported products, this project of our country aimed at the development of a compact size product with less number of elements in line with the situations of Japan. The specific task was to transform the crystal spectrograph of Shimadzu Corporation that had already been produced during wartime into a photoelectric product. Completing two items, one for a single element and the other for 4 elements, we delivered the 4-element type to Nihon Light Metal Co., Ltd. at the end of 1953, and visited their site for installation, as well. I went to the design office of Shimadzu Corporation for more than a year, and had a chance to learn all practices concerned from the development to the completion of spectroscopic instruments. I thank all engineers concerned including those from the production site for lessons given to me and what I learnt through my those experiences, i.e. "drawings are the statement of engineers", "the contribution of research and development is 5%, and the remaining 95% is only achieved by product commercialization efforts", and "the satisfaction of customers is the greatest pleasure for an engineer". It's fun to be involved in production within a corporation, and since I was pleased to be able to offer satisfaction to customers, I thought manufacturing must have suited my nature. In the process of doing such jobs, I became confident of the fact that where devices were first produced was more important than where they were invented.

Joint Research with Hitachi, Ltd. for Far-infrared Spectroscopic Instruments

In 1954, the international joint research of far-infrared spectroscopy between Professor Yoshinaga and Professor Oetjen from the Ohio State University, U.S.A. started, and I took charge of optical design and mechanical design. Since I was in charge of completing the drawings of the precision mechanism and asking the Scientific Apparatus Department of Hitachi, Ltd. (Taga Plant) for its production, I was sent to Hitachi and started to work in front of the drawing board at their Design Department again. This was a joint research project brought by Dr. Isao Makino, the Assistant General Manager of Physical and Chemical Instrument Department at that time (later the General Manager of the Measuring Instrument Division). Dr. Makino was a student of Professor Yoshinaga, who was an assistant professor at the Faculty of Science of Osaka University.

During my stay with them for this engagement, I became keenly aware of the fact that their environment for the development of analytical instrument was really different from that of Shimadzu Corporation. They were just like a footloose and fancy-free mischievous young boy as opposed to a son and heir of a long-established business, and I think that such freewheelingness was reflected in their products, as well. It could be because this Scientific Instrument Department was just a small and terminal department that did not contribute significantly to the profit of Hitachi as a big corporation, and also because Dr. Makino had such a character. It was a real benefit for me to have learnt from such experience in comparing those two companies about the importance of always considering the graduate's aptitude in retrospect of company colors, before sending them to various companies.

Although I had to visit frequently the manufacturing site with some drawings in hand, it was rather congenial to me. I learnt the spirit of manufacturing from manufacturing site workers, and I was greatly moved by the artisan spirit of those workers who were pleased to accept my unreasonable demands.

After my experiences in the study of far-infrared region, I got a job as an assistant professor at The Ohio State University in 1958, and was engaged in the development of a new type of infrared spectrophotometer. After I returned home in 1960, I was involved in joint research with the Optical Device Department of Hitachi' Naka Plant, which had moved to Mito again, in a project related to the commercialization of a far-infrared spectrophotometer for long periods continuously. During such periods, I had an important experience in the patent dispute with PerkinElmer, Inc. (PE). It was also the first time for me to have learnt specifically about a practical method on patent strategy. During this case, fortunately, I made many friends within PE, such as Dr. Savitzky and Dr. Ford.

Prototyping of a New Type of Infrared Spectrophotometer at The Ohio State University

The large-scale single beam far-infrared spectrometer, for which I took charge of design stage prototyping in the previously mentioned far-infrared project, was put to practical use in 1957. As it was the only far-infrared spectrometer available in Japan, many people specialized in molecular chemistry, including the members of

Professor Shimanouchi's Laboratory at the Chemistry Department of the Faculty of Science, as well as Professor Tuboi's Laboratory at the Pharmaceutical Department of the Faculty of Medicine of the University of Tokyo, visited us with samples in their hands. During that time, fortunately, I made many acquaintances in the field of chemistry. While I was engaged in attending to those visitors, I completed my thesis dealing with the photoelectric emission spectrometer, and immediately after that, I left for the U.S.A. I would say the underground research of electronic circuits that I was doing privately late into the night, while being engaged in research as a project member, resulted in the digitization of emission spectrophotometers and became the core of my thesis. (I hear that there are many examples in business enterprises as well where underground research became reality.)

Around 1958 when I left for the U.S.A., Japan was just entering the stage of mass-production for infrared spectrophotometers, but on the worldwide level, the research of infrared devices was nearly saturated. At that time, we got an order from the Infrared Laboratory of The Ohio State University asking to prototype a new large-scale prism infrared spectrophotometer. After an uphill struggle, we worked out a new system that used the double-pass monochromator that Dr. A. Walsh of the National Industrial Science Institute Australia had announced during the years of 1951 to 1953 (generally referred to as Walsh Type) in combination with optical zero-method photometry, and barely saved our faces. At that time, we found that Western companies including PE had already obtained nearly 20 patents for the chopping beam method. Dr. Walsh announced his atomic absorption method in 1955, but he had already made many contributions to the development of monochromators as well.

For some years since then, I participated in the development of high-resolution large-scale diffraction-grating infrared spectrophotometers at The Ohio State University on a three-month contract during summer vacations. While I received various good offers from U.S. spectroscopic-instrument manufacturers, I was not in a position to keep away from Japan for long due to private reasons related to my position as oldest son unfortunately.

Heading for Independent Research Activities as an Associate Professor in 1963

For 12 years after graduation, I was dealing with the development of instruments, i.e. spectroscopic instruments, as a member of laboratory projects. Basically, researchers should invent their own measurement instruments to challenge the unknown world. If they use commercially available measurement instruments, they stand at the same starting line as their rivals. Generally, the inventor of a particular instrument should use that instrument exclusively and keep his or her competitive edge in the research race. Therefore, there are only few researchers in universities who mainly deal with the development of research instruments for the sole purpose of providing such products to other researchers. This is a rather unrefined job and an inefficient way to prepare a thesis.

I became independent as an associate professor, and, since I loved manufacturing more than anything else by nature, I got involved in the development of instruments more than ever, aiming for the establishment of measurement science. Behind the above were the following facts.

- Modern automated instruments at the initial stage of analytical instrumentation imports was unforgettably impressive to me.
- Domestic universities and research institutions were individually dealing with light sources, the spectroscopic system, detectors, optical parts, etc., but they were not dealing with their effective systemization at all.
- The course that I was responsible for was electronic circuits, measurement science, automatic control, etc. , which nobody in the department was able to handle.
- I had many acquaintances amongst analytical instrument manufacturers from my past stay in the U.S.A.

To proceed with the systemization, it is necessary to clarify similarity in spectroscopic instruments that used to be categorized by wavelength range and mutual effect between light and matter, and look at the internal flow of information in a unified manner. Only analog devices were available those days, and I started my research with the prototyping of a simulator for spectroscopic instruments and a system analysis for automated analytical instruments. Then, we made advances in technology from analog to digital, then to the computerization era, and headed for the study of laboratory automation (LA).

On the other hand, the aforementioned underground research that we were dealing with from the days of research into photoelectric emission spectrometer includes fast time-resolved spectrometry. Thanks to extraordinary improvements in photometric accuracy achieved by the employment of a photoelectric system, we got to know the effect that light source variations might have on analytic values. To analyze transient variations in spark sources, time-resolved spectroscopy in microseconds or less was needed, but the microsecond was our limit in those days. Then, after a struggle, we worked out the photomultiplier dinode parallel gate method, by which we achieved a time resolution of 10 nanoseconds for the first time. This achievement got a lot of attention from researchers in the fields of basic chemistry, as well as biology and medical science who had been dealing with the study of free radicals and fluorescence lifetime measurement, and resulted in several kinds of joint research with researchers of medical science. In subsequent studies, we realized resolution close to 1 nanosecond, and eventually, this led to the development of joint research with the Analytical Chemistry Group at the University of Wisconsin. The research of time-resolved spectrometry subsequently resulted in the invention of a photon simultaneous-detection method for the transient observation of ultra-weak light, the invention of a computer-assisted time-resolved photon counting method, etc.

While the ultra-weak spectral photometry technology that I was good at found a way to the microscopic spectral photometry, which then promoted joint research with the medical science group, it seems that my experience in the development of ME equipment in cooperation with a small hut company at the time of preparing the graduation thesis in 1950 survived in the background.

Leading the Way in LA (Laboratory Automation) by Holding the Chair of Measurement Science at the Department of Applied Physics from 1980

I kept holding onto the idea of attempting to improve the accuracy of measurement data by information processing since 1954 when I had started the study of far-infrared light. That was because, suffering from the weakness of light intensity and the poor sensitivity of a detector, I was struggling hard with noise control. As part of the aforementioned systematization study, we initially employed various analog waveform-processing devices, then introduced analog-digital hybrid waveform-processing devices, and eventually from 1970, started to use minicomputers with a scientific research fund.

Since I held a course of lectures, the connection of minicomputers, microcomputers and personal computers with their incorporation into various spectroscopic instruments, as well as computer-based LA, became a core subject of systematization research, and such development was accelerated. Our computer-based LA was characterized by an emphasis on "the indirect attempt to improve equipment performance by numeric data processing" rather than automation. To put it shortly, it was to combine an inexpensive low-performance analyzer with a computer and make it just like a high-end product by means of software. Together with improvement of PC capability, the next stage was to aim for "the development of computer-based new instrumental analysis techniques". Like Fourier spectroscopy as a representative example, various measurement analysis methods based on the newly developed CT photomicroscope and multi-dimension image information also constitute part of these techniques.

The computer-based low-end LA products include virtual and personal-computer instruments, and spectrometers that can be mounted in a personal computer slot. Therefore, we attempted to develop mobile spectroscopic instruments, as well.

Taking a look at the LA system from a computer point of view, you will find that all analytical instruments have a lot of similarities, and, in many cases, know-how available for hardware design and software development, which was obtained in the process of instrument development, is useful for other analytical instruments as well. A concept that takes light beams, charged particles, acoustic waves, etc. within the whole system of analytical instruments as common information flow has the potential of leading to the discovery of a new instrumental analysis method.

Tokyo Forum on Applied Spectrometry

We succeeded in our postwar efforts, which were started with the copying of imported analytical instruments, under the slogan of "catch up with and outrun the technology of foreign products", and manufacturers in our country started to pursue the development of their business to overseas market. In 1965, a panel consisting of manufacturers and users was set up by the instrumental analysis promotion group of members including Professor Kamada of the Industrial Chemistry Department at the University of Tokyo at that time, and Dr. Masiko, Institute Head, and Dr. Saeki, General Manager of Tokyo Industrial Laboratory located in Hatsudai, to gain the trust of foreign users in equipment made in Japan. The first forum was held at Nikkei Hall from November 7 together with the exhibition of the Japan Analytical Instruments Manufacturers Association, aimed at a Japanese version of the famous Pittsburgh Conference. Many people directly in charge of development and design attended from various manufacturers, and discussed with enthusiasm. Since they were all development engineers who had confidence in their competence, they continued to find fault with the instruments of others, and I was impressed by such discussion. It was typically Japanese style in that they all attempted to highlight the best point of performance of their products at the meeting.

Guest Forum The Way to Engineering Spectroscopy

I do not think that there was anybody who argued for "ease of use at the expense of performance" or "ease of maintenance". Although a similar energetic discussion continued for some years since then, as requirements for a needs-oriented approach such as "the customer is always right" built alongside the increase in needs for environmental and medical measurements, manufacturer engineers fell gradually silent. The reason is that many products supplied by manufacturers lost their advantage and consumer-durable-like products rather than industrial goods came to dominate the market.

I remember saying at the convivial meeting of the Tokyo Forum, "Recent spectroscopic instrument manufacturers are producing something like free gifts that come in boxes of caramels", and drew derision from others. But actually, I was thinking it as a testimony to the fact that spectroscopic instruments, which used to be seen as special measuring instruments, were being recognized as general measuring instruments, as I was rather satisfied in my mind with the expansion of low-end products toward the promotion of the engineering spectroscopy. But, on the other hand, it was regrettable that manufacturers were hesitating to introduce those unprofitable high-end products, and engineers were one by one giving up on their artist-like dreams they used to have when they were producing analytical instruments with their individual qualities .

While the Tokyo Forum for applied spectrometry was held repeatedly over a quarter century, every time I visited the U.S.A., I dropped into the house of my awesome friend, Mr. Mitteldolf, President of SPEX, and discussed about the design of distributed spectrometers. I have happy memories of Mr. and Mrs. MittelDolf who provided those artwork-like supreme monochromators to the market without any thought of profit. Now that there is a question of foreign products that occupy our domestic market for high-end products in analytic instruments especially taking an active part in medical and biological fields, I think we should even have an environment such as small manufacturers specialized in analytical instruments; always aiming for the market of highest product categories can mean survival in the market. I expect a lot from the development project of advanced measurement and analysis technology started by JST from 2004.

Figure 4 and Figure 5 show the results of the spectroscopic instrument research for manufacturing, which has been consistently done over the past half century. The research is specifically summarized and

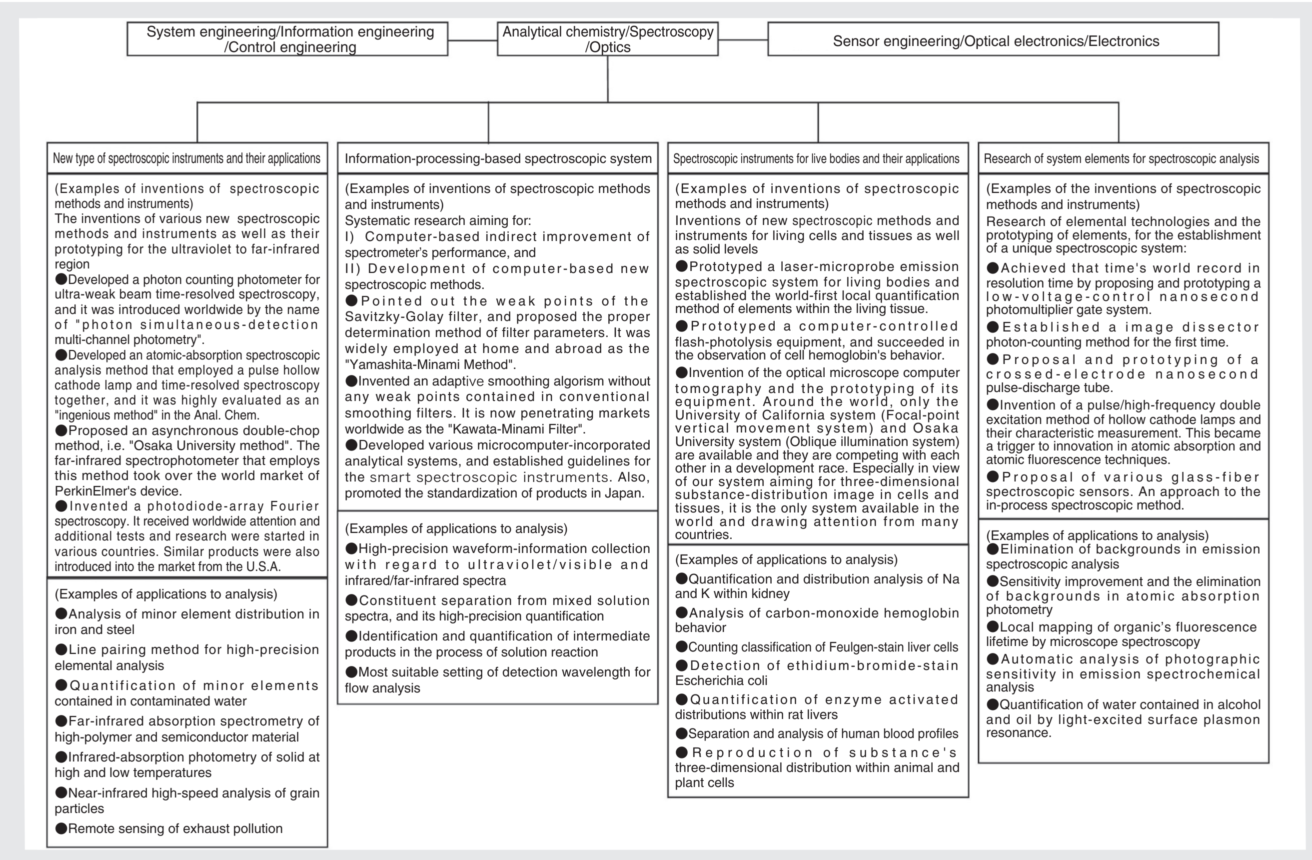

Figure 4 Development of New-principle-based Spectroscopic Instruments and their Applications - History of Research over a Half-century -

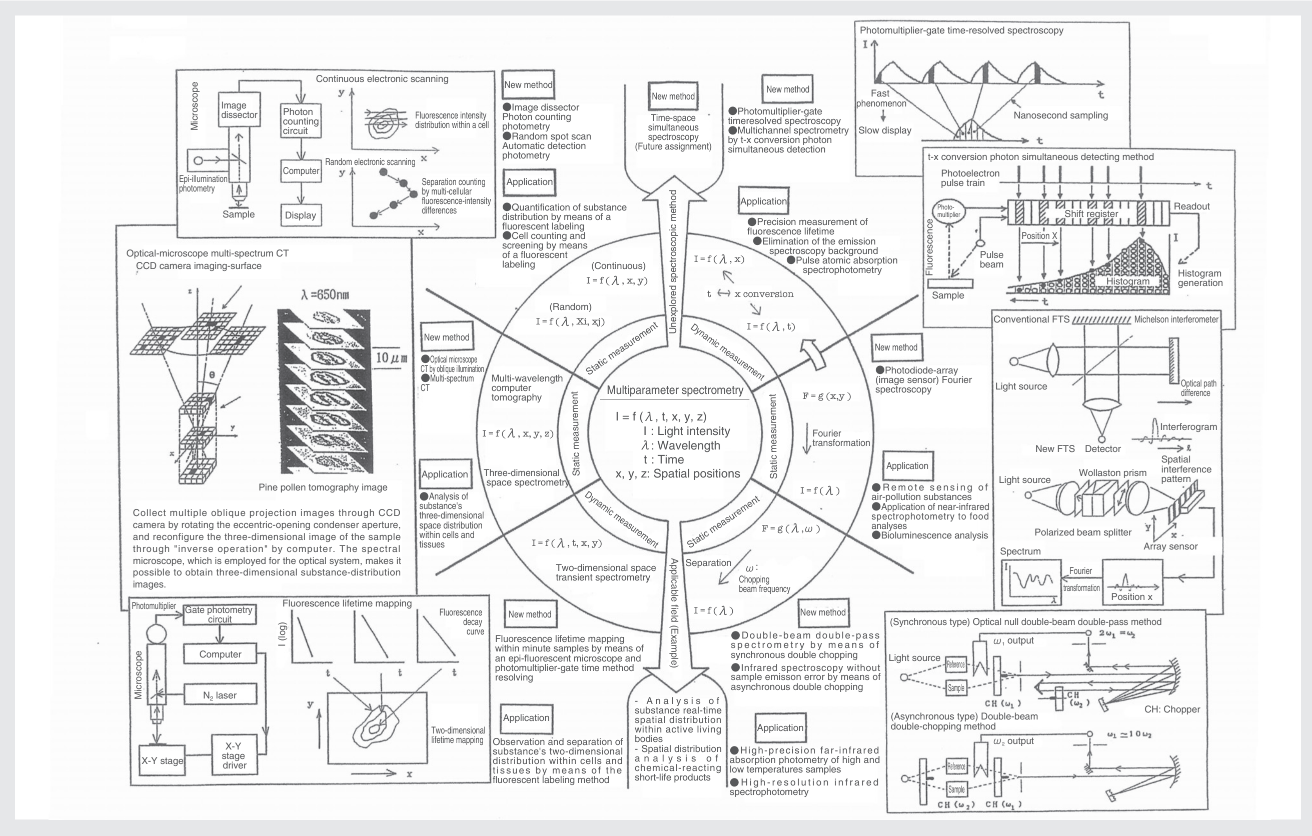

Figure 5 Systemic Illustration of Instrument Development Viewed from the Aspect of Multiparameter Spectrometry

includes applications.

I thus far have talked informally about the history of my research of manufacturing mainly related to spectroscopic instruments, calling for engineering spectroscopy. Needless to say, the basic manufacturers' objective of engineering spectroscopy is to introduce a product into the market one step ahead of competitors and at a competitive price. This principle also applies to when researchers make scientific measuring instruments by themselves. One of the important measures for such a case is a systemic approach, i.e. how well you select elemental technologies and element parts, and how organically you combine them. In the latter half of this paper, I would like to outline systematization methods in a slightly more formal way in reference to my own experiences as well.

Systemic Approach to the Design of Spectroscopic Instruments

These days, a variety of spectroscopic instruments ranging from high-end to low-end products are available, and widely used as normal industrial and medical measuring instruments. Now that spectroscopic instruments are not only used in the environment of research and development as scientific measuring instruments, but also widely used in manufacturing sites as measurement and analysis equipment, the systemic approach has become an essential factor when fundamental research laboratories try to assemble spectroscopic measurement systems or manufactures try to develop and produce spectroscopic instruments. In recent years, due to the development of opto-electronics, a variety of optical parts have become available on the market as shown in Table 1. In addition, since the use of computers and communication systems is increasing more than ever, how organically you combine those element parts to prepare a more value-added system will be the basis of such a field referred to as Engineering Spectroscopy. It is of course important to have sufficient knowledge and understanding on the engineering as a whole, including optics and spectroscopy as well as mechanical engineering, control engineering, electronics, computers, etc.

Breakdown and Block Diagram Mapping

After deciding the purpose and target, select a principle of spectroscopic method. Then, in consideration of performance data and restrictive conditions such as cost, size, etc., which vary depending on the application, either laboratory use or site or field use, decide a configuration framework by breaking the system down (functional segmentation) from the total system into the subsystems and then into element parts, etc.

Table 1 Functional Classification of Optical Parts Commercially Available in the Market

Modes	Types of Effects	Names of Optical Parts
Passive optical parts	Geometric effect	Ordinary lens (Homogeneous), Mirror, Diffraction grating, Aperture-stop beam attenuator, Beam splitter, Filter phase plate, Etalon, Light-path changing prism, Lenticular plate
		Optical fiber, Optical fiber bundle, Optical waveguide, Minute optical element
		Communication optical recomposition parts (Connector, Optical divider/directional coupler, Branching filter)
		Holographic lens, Hologram memory
	Substance effect	GRIN lens, Mirror (Narrow-band), Beam splitter, Filter, Optical fiber (Selfoc), Dispersing prism, Communication optical-circuit part (Optical divider/directional coupler, Branching filter)
		Photographic sensitive medium, Optical disc, Optical card, Thermo-plastic element
		Optical sensor
Active optical parts	Geometric effect	Mechanical shutter, Mechanical modulation and deflection element
		Scanning etalon
		Acoustic optical part (Crystal, Amorphous, Liquid) [Modulation, Deflection, Shutter, Phase conjugation]
		Optical scanning element (Galvanometer mirror, Polygon, Hologram, Digital micro-mirror)
		Communication optical-circuit part [Optical switching, Modulation]
	Substance effect	Electrooptic part (Crystal, Amorphous, Liquid-crystal, Electro-chromic material) [Modulation, Deflection, Shutter, Beam-attenuation, Calculation, Display, Memory]
		Magnetooptic part (Crystal, Amorphous) [Modulation, Deflection, Shutter, Rotator, Beam-attenuator, Memory]
		Nonlinear optical part (Inorganic solid crystal, Organic material/polymer, Gas) [SHG, THG, Parametric oscillation, Optical bi-stability, Shutter, Phase conjugation]
		Stress-optic part (Crystal, Polymer) [Modulation, Deflection, Shutter, Sensor]
		Spatial modulator [Analog, Digital]
		Photochromic element, Electrograph sensitive medium, Opt-magnetic disc
		Laser, LED, CRT, LCD, PDP, SED, ELD, General incoherent source
		Optical sensor [Modulation sensor, Shutter sensor], Optical amplifier
		Optical computer element, Active communication optical-circuit part including OEIC

On the other hand, information-based consideration is needed with regard to the flow of signals within the system. Signals mainly consist of optical signals and electric signals, and an optical sensor is used as their interface. Obviously, as spectroscopic information related to light collecting efficiency is also involved, the whole system's configuration varies significantly depending on which spectroscopic system to select, i.e. single channel, multi-channel, or multiplex.

Figure 6 shows the flow of signals within a spectroscopic system based on substance measurement. The computer data-processing result is directly connected to final objective-substance information or feedback to the signal system, and used for the transformation or modulation of signals. The FT spectroscopy employs the so-called Wiener-Khinchin theory to obtain optical power spectra from the auto-correlation function of optical waves by Fourier transform, and therefore, the spectroscopy system shown in the figure is changed to a two-beam interferometer to obtain the auto-correlation of optical waves. On the other hand, since the diffraction-grating spectroscopic system employs the lens's Fourier transform effect that produces a Fourier transform image with the space grating illuminated by parallel homogeneous-light beams on the spectrum focal plane, it can be regarded as an analog Fourier-transform computer. Since, at present, a computer is one of the element parts incorporated in a spectroscopic measurement system, it may lead to more flexible thinking to collectively understand the signal flow as shown in the figure just as the simple flow of a signal, rather than dividing it into an optical signal and an electric signal.

Selection of the Constituent Element of the Spectroscopic System

Figure 7 shows the aforementioned basic block diagram with each block further broken down into elemental parts. Since the figure is prepared with various types of spectroscopic systems overlapped, it is compatible with most specific systems. The position of a sample varies depending on how mutual effects between light and substance are used, or which spectroscopic system,

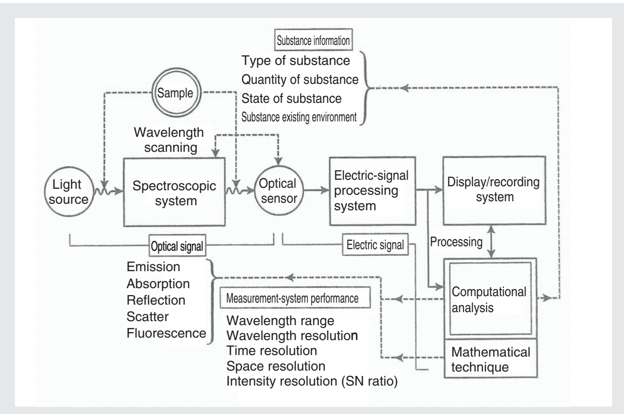

Figure 6 General Configuration of Spectroscopic System and Flow of Signals

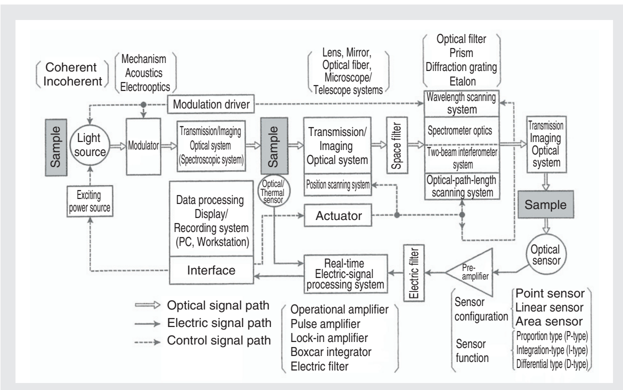

Figure 7 Details of Spectroscopic System's Configuration Blocks

a monochromator or a polychromator. In addition, it is necessary to pay sufficient attention to the positioning of the optical systems related to throughput matching mainly in the spectroscopic system, light leakage that may be caused by stray light, the effect of reflection and dispersion, etc. Proceed with the selection of optical element parts based on the elemental configuration block as shown in Figure 7.

Treatment of Signals in the Electric Signal Domain

A sensor as an interface for transforming optical signals into electric signals should also be selected according to the photometric configuration of a single channel or multi-channels. At this time, a more detailed breakdown is required based on the assumption that sensors are also one of the subsystems. In terms of a system, there are quantum-type and thermal-type single sensors that fall into the classification of Proportional-Type, CCD and MOS image sensors that fall into the classification of Integration-Type, pyroelectric sensors that fall into the classification of Differential-Type, and so on. The way to connect a sensor and a preamplifier is the most important point in terms of S/N, and it should be designed in due consideration of noise figures.

Both microcomputers and personal computers are now important subsystems for a spectroscopic system, and widely used for computation, equipment control, communication, analysis, database management, etc. However, it is not appropriate to rely on computers too much with regard to the process of spectroscopic data sensitivity and accuracy improvement. Especially, since all waveform and image processes are conducted based on a postulated model, you cannot obtain your desired result from any supplied data unless those data are compatible with that model. Noise and false signal sources should be eliminated as much as possible within the spectroscopic system. Therefore, analog systems, such as a lock-in amplifier, a boxcar integrator, etc., are additionally used for that purpose.

Subsystems and composing elemental parts should be selected based on a comprehensive study of respective items shown in Table 2.

Table 2 Technical Considerations for Each Subsystem

Light source (Radiation source)	Radiation propagation media	Radiation collection optics	Spectrometer optics	Detector (Sensor)	Real-time signal processing system (Amplifier system)	Post-processing system/Display system (Computer)
1. Configuration, Size, Distance, Movement 2. Temperature 3. Spectal emissivity 4. Spectral emission characteristic 5. Temporal characteristic	1. Spectal emission of radiation propagation media 2. Propagation length 3. Spectral transmittance	1. Field of view 2. Spatial scanning mode 3. Spatial scanning range 4. Out-of-sight emission removal capability	1. Wavelength range 2. Wavelength resolution 3. False emission (stray light, high-order light, etc.) removal capability	1. Spectral sensitivity range 2. Absolute sensitivity 3. NEP, D* 4. Operating temperature 5. Background emission 6. Frequency response 7. Number of elements	1. Detector - Preamplifier matching 2. Voltage/Current gains 3. Frequency response 4. Filtering 5. Phase sensitive detection	1. Output voltage range 2. Signal source impedance 3. Control system 4. Memory system 5. Communication system 6. Display system 7. Numerical processing algorithm

NEP : Noise equivalent power. Input power needed to obtain any output equivalent to the noise.
D* : Specific detectivity. Used to compare different square-measure detectors.
$D^* = A^{1/2}/NEP$ (A: Detector's square measure)

Conclusion

I am grateful for the development of peripheral technologies extensively from the light-source to the radiation transfer media, the spectroscopic system, the detector system, and the signal processing system, i.e. the emergence of photo-multiplier tubes, transition from analog to digital electronics, the rapid development and penetration of computers, the emergence and penetration of lasers, the development of optical-fiber technologies, the penetration of high-performance diffraction grating and the emergence of Fourier spectroscopic system, the penetration of various semi-conductor sensors (including image sensors), and so on. I am pleased that I was able to make the most of that drastic transition time of technologies to deal with my own research.

Now that I'm coming up for "Kiju", my 77th birthday, I am going to dedicate myself further to the establishment of low-end markets in various spectroscopic technologies, the development of field-use mobile spectrometers (including clinical devices), the development of homeland security instruments, etc. from now on. I am willing to keep at least my manufacturing spirit in the future by getting stimulus from young engineers.

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