A Grating-Based Spectral Filtering Project in Photonics Instrumentation

Gao-Wei Chang, Zong-Mu Yeh, Yu-Hsuan Lin, and Hsiu-Ming Chang

Abstract—In response to the growing demand of photonic systems engineers in industries, this paper proposes a term project that helps students gain insight into photonics instrumentation via a grating-based spectrometer. The students are guided through simulations and experiments for the spectral filtering system and then implement the spectrometer using some technical notes and testing kits. They perform experiments and tests to verify and refine their works. A contest is held at the end of the course where the measurement accuracy and repeatability of the proposed systems are evaluated. This project has been used for two semesters, and both the instructors' and the students' feedback are discussed.

Index Terms—Photonics education, photonics instrumentation, project-based learning.

I. INTRODUCTION

In recent years, photonics has become increasingly important in the engineering world [1], [2], and its systems technologies have contributed greatly to various areas, e.g., surgery, consumer electronics, automatic control, and fiber-optic communication. Photonics products, such as digital video cameras, CD/DVD players, and thin-film-transistor liquid-crystal displays (TFT-LCDs), have brought great convenience to daily lives. Photonics instrumentation has offered an excellent solution to fabrications and measurements for the related industries [3], [4].

Regarding photonics systems, Kincheloe et al. [5] organized a special program to train students to be photonics technologists. Johnstone et al. [6] presented photonics laboratories with emphasis on optical communication systems. Uherek and Donoval [7] reported curricula with optoelectronics education and two individual student's projects on photonics systems. Schmalzel and Dyer [8] thought that teaching instrumentation is a challenge because there are many topics that should be considered or covered. For example, polarization of light can measure the thickness of thin films in an ellipsometer. In addition, white light interferometry can measure the surface structure of objects within a nanometer scale [9].

Usually, photonics systems (e.g., photonics instrumentation), involving optics, mechanics, and electronics, can serve as optomechatronics systems. Their basic configuration is depicted in Fig. 1. Spectroscopy [4], [10] has been widely recognized as a very important technique in photonics instrumentation because of its diverse applications, such as color measurement and ellipsometry, as shown in Fig. 2. Usually, it employs a grating to realize a spectral filtering system, called grating-based spectrometer.

Since the photonics systems technology is a multidisciplinary subject, it needs a course, e.g., mechatronics engineering, to help junior or senior students develop such a system. They are supposed to experience at least the courses shown in Fig. 3. Project-based learning (PBL) has been acknowledged as a methodology whereby they apply, learn, and integrate their knowledge in a coherent and meaningful way [11]–[13]. In other words, it offers them an opportunity to link the different disciplines and to gain the knowledge and the practical skills of the individuals. Dyer and Schmalzel [14] used PBL to motivate students and affirm course contents in instrumentation education, and they had good feedback from students.
This paper proposes a grating-based spectral filtering project to achieve the multidisciplinary goal. Since the spectral-filtering technique of the project is crucial to the photonics instrumentation in the industrial applications, e.g., color display, fiber-optic communication, and thin-film technology [4], students are encouraged to extend the proposed technique to the related measurement systems, e.g., TFT-LCD spectral colorimeter, optical spectrum analyzer, and spectral ellipsometer, as shown in Fig. 2. In other words, once those students have the ability to develop a grating-based spectrometer, the knowledge is easier to transfer to develop more sophisticated ones. Therefore, the main difference of the proposed project from others is that it is transferable and its significance is obvious.

Several educational objectives are to be achieved in the project. First, the students will learn how to design and implement photonics or optomechatronics systems. As a result, this project enables them to practice and combine various knowledge and practical skills into photonics instrumentation. Second, students will learn photonics experimentation and instrumentation to achieve multidisciplinary education. In the project, students will verify and compare their works with commercial products and learn from this process how to improve their own designs. Finally, students will learn how to write and present their research results. For each task of the project, a report or a presentation is required. With proper guidance and feedback from instructors, students can improve their writing and presentation skills and their teamwork ability.

This paper is organized as follows. The project organization is presented in Section II. Project tasks are described in Sections III and IV, respectively. Section V offers the assessment and discussion for the project. Finally, the paper ends with a conclusion in Section VI.

II. ORGANIZATION OF THE PHOTONICS INSTRUMENTATION PROJECT

The project is designed for a Mechatronics Engineering course for junior and senior students in the authors’ university. Students have taken courses in general physics (including the part of optics), programming language, microelectronics, and microprocessors, as shown in Fig. 3. Experience in photonics or optics courses may not be required. The project development procedure is presented in Fig. 4, and it is divided into several tasks, as listed in Table I.

In Task 1, the theoretical basis of gratings is reviewed for the project. The grating-based spectral filtering system is to perform automatic spectral measurement, to manipulate and display measured data through a graphical user interface (GUI) and to communicate with a PC. In addition, its measurement accuracy and repeatability in the visible range [400, 700 nm] are required to be compared with those from a commercial spectrometer (e.g., a Photo Research Company’s PR650 spectrometer).

The gratings and the spectral filtering module are simulated in Task 2. Task 3 contains the three subtasks, optics experimentation, electronic hardware, and software, indicated in Fig. 4. In this task, students are divided into groups of three members, each in charge of their individual subtasks. The group members cooperate to integrate the optics module and the electronic system, and then to test the proposed spectrometer. To offer a relative and meaningful evaluation on the measurement results from their spectrometers, a contest, designated as Task 4 in Table I, replaces the final exam. Students should present their results or write a report on what they have learned, and their results will be graded according to the grading policy, as indicated in Table I. Table II lists the scoring rule for the contest.

Teaching assistants are responsible for keeping track of each group’s work, making sure they can meet the deadline for each task.

III. DEVELOPMENT OF A GRATING-BASED SPECTRAL FILTERING MODULE

Before the project starts, students should know the theory of a grating in the optics part of general physics. However, the instructor should review the theory in the beginning of the course. Basically, the two kinds of gratings are transmission grating and reflection grating. A transmission grating may be regarded as an optical component with many slits of very small widths. Several approaches have been proposed for analyzing them [15]–[17]. A simple approach from general physics [15], [16] is for students to begin with studying diffraction by a
TABLE I
ORGANIZATION OF THE PROJECT

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Weeks used</th>
<th>Task</th>
<th>Grading policy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>Theoretical review of diffraction, interference and gratings, system function and requirement</td>
<td>10 points (quiz)</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>Simulations of gratings and grating-based spectral filtering modules</td>
<td>15 points (individual work)</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>Development of the grating-based spectrometer (including optics experimentation, and electronic hardware and software implementation)</td>
<td>35 points (on group basis)</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>Contest (final exam.)</td>
<td>40 points (on group basis)</td>
</tr>
</tbody>
</table>

TABLE II
SCORING RULE FOR THE CONTEST

<table>
<thead>
<tr>
<th>Item name</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accuracy of measurement</strong></td>
<td></td>
</tr>
<tr>
<td>Full points are given when the average measured data from the student spectrometers have less than a 5% difference compared to those of the references measured by a PR650 spectrometer (five points are counted). Five points are deducted for each 5% difference in measurement.</td>
<td>40 points</td>
</tr>
<tr>
<td><strong>Repeatability of measurement</strong></td>
<td></td>
</tr>
<tr>
<td>Full points are given when average standard deviation of measurement results is less than 3% for 10 measurements at different times. Ten points are deducted per 3% increment of variation.</td>
<td>40 points</td>
</tr>
<tr>
<td><strong>User review</strong></td>
<td>20 points</td>
</tr>
<tr>
<td>Peer review and instructor’s evaluation for the items of groups technical manuals, such as its completeness, clarity and arrangement.</td>
<td></td>
</tr>
</tbody>
</table>

![Fig. 5](image)

**Fig. 5.** Simulation procedure for learning the grating topics.

single slit of finite width and interference by two (or multiple) slits of infinitely small widths. Such a study on single-slit diffraction, Young’s double-slit interference (YDI), and multiple-slit interference (MSI) can be extended to the treatment of multiple-slit diffraction, as shown in Fig. 5. With this approach, students are able to grasp more easily the idea of a grating because no complicated mathematical formulation is involved. Specifically, both diffraction and interference may simply be treated as a supposition of waves of light. The former originates from a continuous distribution of light sources (e.g., that of light going through a single slit of finite width), while the latter results from a discrete number of sources (e.g., those emerging from multiple slits of infinitely small widths). Consequently, the irradiance as a result of multiple-slit diffraction can be regarded as a composite result from single-slit diffraction and MSI. Its spatial distribution can be easily obtained by means of some mathematical tools (e.g., MATLAB). Fig. 6(a) displays the relationship between the irradiance distribution and the number of slits \( N \) for a specified wavelength \( \lambda \) (400 nm).

Obviously, as the value of \( N \) increases, the lobes of the distributions become narrower, and thus the spatial resolution of irradiance corresponding to a wavelength becomes finer. In other words, for diffraction of monochromatic light by a large amount of slits (or by a grating), the irradiance corresponding to a diffraction order \( m \) is confined to a very small spot size, and thus the diffracted light of a given wavelength is projected to a certain location dependent on the order or a certain diffraction angle \( \theta_m = \sin^{-1}(\sin \theta_i + m\lambda/d) \), where \( \theta_i \) stands for the angle of incident light to the normal of the slits (or a grating),

![Fig. 6](image)

**Fig. 6.** Comparisons of spectral filtering effects through (a) simulations for different numbers of slits and (b) a simulation for the resolving power to different wavelengths of light.
and \( d \) means groove pitch \([15]–[17]\). For diffraction of polychromatic light by a grating, the irradiance distribution of the diffracted light appears to disperse at various diffraction angles corresponding to its individual wavelengths, within a certain diffraction order. This technique is the basic idea of spectral filtering from a grating. For a better understanding of the spectral filtering property of gratings, a theoretical discussion and the simulations of gratings are assigned as Tasks 1 and 2, respectively.

A. Task 1: Theoretical Discussion of Diffraction, Interference, and Gratings

In Task 1 of the project, students will explain the theoretical basis of interference, diffraction and gratings by consulting the related texts and the given websites, which are “Amplitude of Interference,”” “Young’s Double Slit Interference,” “Single Slit Diffraction,”” “Multiple Slit Diffraction,”” and “Diffraction Grating Calculator.” They are asked to deliver a report in which the simulation results from the websites and the theories are discussed. Each student is required to perform the task and is graded individually.

The purpose of this task is to let students understand thoroughly these theories so that they can move on to the following tasks. Students should review the theories since most of the students are seniors and the rest are juniors, who have had exposure to the diffraction and interference of light in their general physics course.

B. Task 2: Simulations of Gratings and Grating-Based Spectral Filtering Modules

Computer simulation is one of the efficient ways for students to understand the theories better. In Task 2, students perform three required simulations of gratings and a simulation of grating-based spectral filtering modules. Then, they write a report to discuss their results and what they have learned. Students are encouraged to perform the simulations with the programming language with which they are familiar so that they can easily meet the deadline. These simulations are described in the following.

1) Grating Simulation 1: Multiple-Slit Diffraction: As shown in Fig. 5, students are asked to simulate single-slit diffraction, YDI, and MSI (for at least three different numbers of slits). Then, they simulate multiple-slit diffraction for different numbers of slits \( N \) (e.g., 20). The simulation results are shown in Fig. 6(a). Finally, they are required to discuss the simulation results and to try to explain and anticipate what will happen when the number of slits increases or decreases. In this simulation, they can gain a better understanding of interference and diffraction.

2) Grating Simulation 2: Resolving Power: The resolving power of a grating is very important for spectral filtering. On the basis of the first simulation, students are asked to simulate multiple-slit diffraction for different wavelengths of light and a given number of slits. In their reports, they need to draw conclusions about the resolving power for a grating and compare the results with the related theories. A simulation result for red light (wavelength 700 nm) and green light (wavelength 500 nm) is shown in Fig. 6(b). They are expected to find that the resolving power increases with the increment of the number of slits. Through this simulation, the concept of resolving power is better understood and will help the students choose a proper grating.

3) Grating Simulation 3: Angular Dispersion: Angular dispersion reflects the performance of spectral filtering. In this simulation, the students can learn that the diffraction of grating at a higher order yields greater dispersion of light. Fig. 7 shows that a larger dispersion corresponds to a higher diffraction order, because the incident light is normal to the surface of the grating. Students should obtain the diffraction angle of the dispersed light for at least four different wavelengths. They should discuss the simulation results for angular dispersion.

4) Simulation of Grating-Based Spectral Filtering Modules: Gratings have been widely used in instruments such as spectroscopes, spectrographs, or spectrometers \([15]\). A spectrometer is designed to detect and transmit the electromagnetic spectrum of a measured component. The Czerny–Turner (C–T) configuration is one of the commonly used structures in a spectrometer, as depicted in Fig. 8. The use of mirrors in the C–T structure makes it more adjustable than others \([17]\). Light comes from a wide-band light source, and it is focused by the mirror M0 through an entrance slit and projected to a collimating mirror \( M1 \). A collimated light beam is then incident upon a grating and dispersed because of different angular dispersions of different wavelengths of light. The dispersed light is then projected onto a focusing mirror \( M2 \). As the reflected light from \( M2 \) is incident on a linear charge-coupled device (CCD), then the dispersed components of the light correspond to individual pixels of the sensor. This process is the basic working principle of the optics module of a spectrometer. As shown in Fig. 9, if the linear CCD is replaced with a slit, called
exit slit, and if the grating is equipped with a rotary device (e.g., a stepping motor), the optics module can work as a monochromator, since the module only acquires one wavelength at a time. Because the width of the exit slit in the optical system is rather small, only a certain wavelength of light can pass through the slit. Therefore, the C–T configuration with an exit slit, or the monochromator, is sometimes regarded as a calibration device for a spectrometer. If another wavelength is desired, the grating is simply rotated until the desired wavelength comes out from the exit slit.

As shown in Fig. 8, the C–T configuration is considered as a grating-based spectral filtering module. Students are required to simulate it using ASAP software by Breault Research Organization, Inc., Tucson, AZ. The authors have recorded a series of “Beginner’s ASAP” computer-aided instruction (CAI) and put them on the course website. Students who are enrolled in the class can gain access to the website and learn how to use the software. Even those who are not required to do the simulation are encouraged to study the software. A teaching assistant is responsible for managing the ASAP license and for guiding the students to go through the simulation.

An example of the simulation result is shown in Fig. 9. Students write the individual simulation results in their reports and analyze the phenomena they have observed. ASAP is one of the widely used software programs for analyzing optomechanical systems. Students will learn the script language of ASAP to de-
sign their optical systems. However, the simulation using this software is optional since it may be not available in most universities. Without the ASAP simulations, the spectrometers can also be developed with the help of well-designed experimentation.

IV. DEVELOPMENT OF A GRATING-BASED SPECTROMETER (TASK 3)

According to the system design procedure of this project, as depicted in Fig. 4, one student in each group is in charge of the optics module experimentation. At the same time, the other two members are responsible for developing the electronic system of their spectrometer (including hardware and software). Finally, the optics module and the electronic system are integrated and tested to evaluate the performance of their spectral measurements.

A. Optics Module Experimentation

The aim of the optics experiments is to assess the characteristics of the key components, the grating, and the linear CCD, by simple testing kits or devices (e.g., Roscolux color filter no. 15 and Welch Allyn lamp 1100-U) so that the spectral filtering performance of their spectrometer can be as accurate as possible. Fig. 10 shows the experiment procedure. The procedures are conducted on optical breadboards with some optical components and mechanical assembly (e.g., iris, post, and holder). Proper determination for some specification of key optical components, e.g., that of a grating, will make the experiments easy to handle. For example, a bladed grating (Edmund Scientific Company A46-077) is adopted to yield a uniform angular dispersion in the wavelength range 380–780 nm, and the groove density influences its resolving power.

1) Experiment 1:

a) Testing the Angular Dispersion of the Grating: Rotate the grating of the optics module that is equipped with an exit slit, and measure the dominant wavelength of the incident light, which is diffracted by the grating and then spatially filtered by the exit slit, as shown in Fig. 9.

b) Determining the Resolving Power: Put an aperture stop equipped with an iris diaphragm in front of the grating so that the beam size of the light incident upon the grating can be adjusted by changing the aperture size; redo part a) in this experiment and then compute the resolving powers because of the effects of different aperture sizes.

As shown in Fig. 11, the experimental results were taken from a project group as an example. This figure displays the angular dispersion of their grating. Obviously, it is almost linear as a consequence of the grating selection. In addition, this figure shows that the resolving power becomes better as the grating is equipped with an aperture stop of a larger diameter. Under the condition of the same rotation angle, this shows wider spectrum
Fig. 14. Schematic diagram of the electronic circuits.

Fig. 15. GUI of a student’s spectrometer.

dispersion. This example explains the consistency of the theory and practice for gratings.

2) Experiment 2: Evaluating the Diffraction Efficiency $I_1/I_{ink}$: Diffraction efficiency of gratings may be regarded as relative spectral response. First, record the intensity of the light of the diffraction order 1, denoted as $I_1$, for each wavelength in part a) of Experiment 1 and then evaluate the ratio of the intensity to that of the incident light $I_{ink}$ with respect to wavelengths. Notably, the light dispersed from a bladed grating is mainly composed of its spectral components of a given diffraction order (e.g., order 1) [17]. Fig. 12 indicates a measurement result for diffraction efficiency. This experiment may be skipped if a commercial spectrometer for calibration is not available. Alternatively, the composite spectral responses of the grating and the CCD can be estimated with the help of Experiment 3 to evaluate the performance of the proposed spectrometer.

3) Experiment 3: Estimation of the Spectral Response of a Linear CCD: First, acquire the readouts from the linear CCD in response to the spectrally filtered light that is dispersed on its individual pixels and then estimate the spectral response of the CCD with the diffraction efficiency evaluated previously. Fig. 13 shows the spectral response of a linear CCD. As mentioned in Experiment 2, the composite response can be obtained by this experiment; and as a result, the spectral filtering performance of the optics module can be evaluated.
B. Electronic Hardware and Software Implementation

The microcontroller 89C51 has been widely recognized as an easy-to-use vehicle to develop an electronic platform because it contains the functions of primary peripherals for computer organizations, e.g., memory and input/output ports, in a single chip. The students in this course are supposed to have experiences in developing the hardware and software for the single chip applications. Fig. 14 shows a schematic diagram of the electronic circuits for this project. The GUI of a proposed spectrometer is programmed by Microsoft Visual Basic, as shown in Fig. 15. The manipulation of measured data (e.g., storage and transmission) can be easily achieved through the interface. Prior to the integration of the optics module and the electronic system, the hardware and software can be tested individually to see if they work properly.

C. System Integration, Test, and Evaluation

An integrated system from the project groups is taken as an example to demonstrate the effectiveness of the system integration, test, and evaluation. Fig. 16 displays a photograph of the spectrometer. Fig. 17(a) and (b) shows the calibrated spectra of the light emitted from a tungsten halogen lamp without and with a filter.

Table III

<table>
<thead>
<tr>
<th>Item</th>
<th>Avg. Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy in measurement</td>
<td>72</td>
</tr>
<tr>
<td>Repeatability of measurement</td>
<td>89</td>
</tr>
<tr>
<td>User's manual</td>
<td>83</td>
</tr>
</tbody>
</table>
TABLE IV
EVALUATION OF THE FIRST 90 STUDENTS WHO PARTICIPATED IN THE PROJECT

<table>
<thead>
<tr>
<th>Questions posed</th>
<th>Average*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you understand more in related theories after this project?</td>
<td>8.2</td>
</tr>
<tr>
<td>Do you think that the simulations and experiments are beneficial to your project?</td>
<td>8.6</td>
</tr>
<tr>
<td>Overall, how difficult did you find this project (the higher score means more difficulty)?</td>
<td>7.5</td>
</tr>
<tr>
<td>Overall, how interesting did you find this project?</td>
<td>8.7</td>
</tr>
<tr>
<td>Overall, how would you rate this project?</td>
<td>8.2</td>
</tr>
</tbody>
</table>

* Learners evaluate this system in 0-10 scores where 10 is the highest score.

V. ASSESSMENT AND DISCUSSION

A. Assessment

The project has been carried out twice in the course with a total of about 90 students at the authors’ department of the National Taiwan Normal University, Taipei, Taiwan, R.O.C. An anonymous questionnaire is given for students to assess the project at the end of each term. The assessment from the instructor and the students are discussed below.

1) By Instructor: Nearly 30 spectrometers have been made for this project in the past two years. Two groups failed to implement a spectrometer. One of them failed because they did not set proper test points in their circuits. The other group had trouble controlling the rotation of the grating. The scores of the students are evaluated according to Table I and, in particular, the average scores of the contests according to Table II are shown in Table III. The instructors are pleased with the students’ measurement results in view of the work from undergraduate students. Overall, the measurement repeatability is indeed satisfactory. The improvement on accuracy may be arranged as a part of the future work.

2) By Student: This project had an overall positive feedback from the students. The results of the anonymous questionnaire are shown in Table IV. This project has been carried out for over two years. The students thought it was interesting (scoring 8.7) but somewhat difficult (scoring 7.5); however, students give this project an overall high score of 8.2.

Although there was space for additional comments on the questionnaire, most students did not make any comment. However, their reports often contained comments. Their suggestions were very important for authors to make improvements on the projects. Some comments are as follows:

- “It’s a pity we did not get enough knowledge of optics in general physics. It would be better if we took some introductory courses to optics.”
- “The project is tough, but interesting. We can’t believe we succeeded. Now it seems that making an instrument is not so hard.”
- “If we had gotten more time, we could have done a better design.”
- “I like the feeling of understanding to theories, simulations, and implementations through the cooperation with group members; it is very interesting.”

B. Discussion

This project has been designed to develop photonics instrumentation for junior and senior students. According to the authors’ assessments, it was favorably rated by the instructors and students. The students liked comparing their works with each other. The authors observed that the students indeed made great progress on technical skills for designing optical systems, implementing signal processing circuits, and writing programs. This comparison verifies the effectiveness of PBL. It provides the students with a chance to link various disciplines and to gain the knowledge and the practical skills of the individuals.

Although a spectrometer is only one class of photonics instruments, it can be extended to a variety of photonics instruments, e.g., reflectometer, ellipsometers, and optical spectrum analyzer in fiber-optics communication. In addition, by introducing the application of spectrometers to industries, students will have more motivations to do the work.

VI. CONCLUSION

This project has been proposed for introducing photonics instrumentation to the students. It provides them with an opportunity to apply, learn, and link their knowledge from different courses, in a coherent and meaningful way. They also learned a general methodology for photonics instrumentation by the grating-based spectrometer. In addition, their presentation and writing skills are improved through practice and feedback from the instructors and classmates. The project has been carried out for two terms and was favorably evaluated by the students. Teachers are welcome to contact the authors for more information on this project.

ACKNOWLEDGMENT

The author would like to thank the Academic Paper Editing Clinic at National Taiwan Normal University (NTNU). The authors would also like to thank the teaching assistants K.-D. Ciou and H.-Z. Kuo for coordinating the project tasks.
REFERENCES


Gao-Wei Chang received the Ph.D. degree in electrical engineering from National Tsing Hua University (NTHU), Taiwan, R.O.C., in 2000.

From 1991 to 1998, he was with the Opto-Electronics and Systems Laboratory (OESL) and the Center of Measurement Standard (CMS) in Industrial Technology Research Institute (ITRI), Taiwan, R.O.C. He is currently an Associate Professor in the Department of Mechatronic Technology of National Taiwan Normal University (NTNU), Taipei, Taiwan, R.O.C. His research interests include optical signal processing, optoelectronics system design, and automatic testing and measurement.

Zong-Mu Yeh received the M.S. degree in electronics engineering from the National Taiwan University of Science and Technology, Taipei, Taiwan, R.O.C., in 1982 and the Ph.D. degree in industrial technology from Iowa State University, Ames, in 1992.

He is currently a Professor in the Department of Mechatronic Technology and the Department of Industrial Education of the National Taiwan Normal University (NTNU), Taipei, Taiwan, R.O.C. His research interests include mechanical computer interface, fuzzy control, digital signal processing and e-learning.

Yu-Hsuan Lin received the B.S. degree in automatic engineering from the National Formosa University (NCTU), Huwei, Taiwan, R.O.C., in 2001. He is currently working toward the M.S. degree at the National Taiwan Normal University (NTNU), Taipei, Taiwan, R.O.C. His main interest is optomechatronics.

Hsin-Ming Chang received the B.Eng. degree in electrical and electronics engineering from the National Taiwan Normal University, Taipei, Taiwan, R.O.C., in 2002. He is currently working toward the M.S. degree in electrical engineering at Stanford University, Stanford, CA.