ADAS/AD に向けた革新的な車載カメラシステム「Tele & Wide 同一光軸カメラ」の開発

金岡浩史，倉茂孝道，髙梨祐介，目黒明彦，築山大亮，和湯瑞葵

Innovative In-vehicle Camera System for ADAS/AD: Single-Lens System Integrating Telephoto and Wide-Angle Functions

Hiroshi KANAOKA, Takamichi KURASHIGE, Yusuke TAKANASHI, Akihiko MEGURO, Daisuke TSUKIYAMA and Mizuki WAYU

自動車業界における先進運転支援システムや自動運転技術は日々進化している．また，ドライバーが標識や歩行者等を視認できないことで発生する重大事故を防止するため，視認性を向上させる手段へのニーズが高まっている．

ニコンと三菱ふそうトラック・バス株式会社は，未来のトラックやバスに新たな価値を創出することを目指し，2020年から共創活動を行ってきた．その成果として，望遠レンズと広角レンズを一体化し，遠方と周辺を確認することが可能となる革新的なカメラシステムを確立した．

この革新的なカメラは望遠レンズと広角レンズの一体化を実現し，遠方と周辺を同時に撮影することが可能である．遠方と周辺の光軸が同一のために視差が生じないことから車両周辺の情報を画像認識する際に，遠方で認識した標識や他車をトラッキングしても，対象を見失ったり二重に認識したりする問題を減らすことができる．また，効果的に車両に配置することによりカメラ台数を抑えながら全周囲360°を途切れなく見ることができ，従来の課題であったシステムコストや故障率などの低減が期待できる．

In the automotive industry, advanced driver-assistance systems (ADAS) and autonomous driving technology (AD) are evolving every day. Moreover, a growing demand exists for methods that enhance visibility to prevent serious driver-accidents related to unnoticed signs/pedestrians. Nikon and Mitsubishi Fuso have developed an innovative in-vehicle camera system to create new safety value for future trucks and buses.

The initiative resulted in the development of an innovative camera featuring a single-lens system integrating telephoto and wide-angle functions to facilitate both long-distance and peripheral visibility.

The optical axes of the far-away and periphery shots are the same, which prevents parallax. Therefore, the camera system reduces the risk of losing track of an object or detecting a double image when used as an in-vehicle camera with AI image recognition to collect road information with tracking signs or other vehicles in the distance.

Using this system requires fewer cameras to be installed in the vehicle owing to its effective positioning and integrated telephoto and wide-angle lens system. This innovation facilitates uninterrupted 360° coverage and addresses common challenges such as high system costs and failure rates.

Key words 車載カメラ，先進運転支援システム，自動運転，望遠，広角，同一光軸
in-vehicle camera, advanced driver-assistance systems, autonomous driving, telephoto, wide-angle, coaxial

1 Introduction

In the automotive industry, advanced driver-assistance systems (ADAS) and autonomous driving technology (AD) are evolving every day. Moreover, a growing demand exists for methods that enhance visibility to prevent serious driver-accidents related to unnoticed signs/pedestrians.

Nikon and Mitsubishi Fuso have developed an innovative in-vehicle camera system to create new safety value for future trucks and buses. The initiative resulted in the development of an innovative camera featuring a single-lens system integrating telephoto and wide-angle functions to facilitate both long-distance and peripheral visibility (Fig. 1).

The optical axes of the far-away and periphery shots are

Fig. 1 Tele & Wide coaxial camera integrating telephoto and wide-angle lenses

the same, which prevents parallax. Therefore, the camera system reduces the risk of losing track of an object or detecting a double image when used as an in-vehicle camera with AI image recognition to collect road information with tracking signs or other vehicles in the distance (Fig. 2). Using this system requires fewer cameras to be installed in the vehicle owing to its effective positioning and integrated telephoto and wide-angle lens system. This innovation facilitates uninterrupted 360° coverage and addresses common challenges such as high system costs and failure rates.

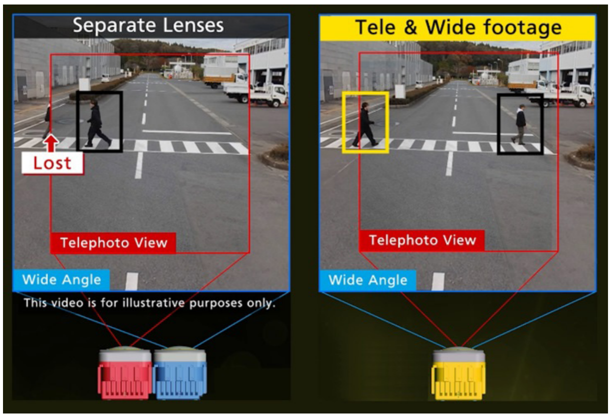


Fig. 2 Comparison between separated telephoto and wide-angle lenses (left) and coaxial configuration (right) (coaxial configuration is free from parallax effects)

2 Tele & Wide Coaxial Camera

The wide-angle lens is designed with a FOV of 190° and the telephoto lens with a FOV of 20°. The light from each lens enters from the object side, passes through a common lens group, and is then split into separate optical paths by a beam splitter. The reflected and transmitted light from the beam splitter passes through subsequent lens groups and is then focused onto the image sensors (Fig. 3). This configuration enables the acquisition of parallax-free images for both the wide-angle and telephoto views. In addition, considering factors such as downsizing the housing and manufacturability of the lenses, the reflected path is assigned to the wide-angle lens and the transmitted path to the telephoto lens.

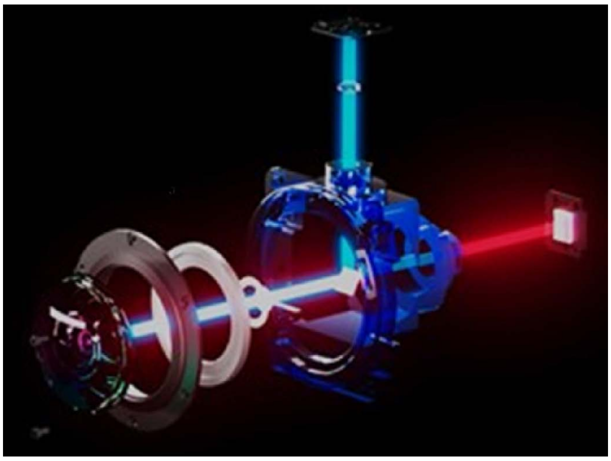


Fig. 3 Configuration of the Tele & Wide coaxial camera

Considering in-vehicle applications, the optical design was advanced with careful consideration of the following six points:

1) Projection Characteristics of the Fisheye Lens

As mentioned above, the wide-angle lens of this camera is a fisheye lens with a FOV of 190°. A fisheye lens can be designed to alter its projection characteristics, allowing it to enlarge the central area of the image while compressing the periphery, or achieve the opposite characteristics. Because this camera is configured to enlarge the central area of the image with the telephoto lens, it is desirable for the wide-angle lens to provide higher resolution in the peripheral areas than in the center. Based on this concept, the wide-angle lens was designed with projection characteristics that enhance resolution in the peripheral areas of the image.

2) Resolution Performance

To enable object detection across the entire image, the optical design ensures high resolution not only in the center but also in the peripheral areas. In particular, because it is necessary to satisfy the performance requirements of both the wide-angle and telephoto lenses, the common lens group located before the beam splitter was designed with an optimal lens power that balances the wide-angle and telephoto performance. Considering maintainability, the design has been implemented to make the front lens replaceable, while suppressing resolution degradation caused by mounting errors.

3) Optimal Sensor Placement

This camera is intended for installation outside the vehicle, where dust, dirt, water droplets, and similar contaminants are likely to adhere to the front surface of the lens. If the sensor is positioned to focus on nearby objects, any adhering contaminants become more conspicuous, whereas positioning the sensor to focus on distant objects reduces detection accuracy for nearby objects.

Based on these considerations, the sensors are positioned at locations optimized for the intended use cases.

4) Robustness to Temperature Variations

When the environmental temperature is high or low, focus shift may occur, resulting in image quality degradation. This camera employs a robust design that minimizes image quality degradation in high- and low-temperature environments by selecting materials and shapes for optical and mechanical components with consideration of their thermal deformation characteristics.

5) Ghost and Flare

We took measures to minimize the occurrence of ghosting and flare, which can be detrimental to object detection. In particular, because a fisheye lens has a wide FOV and is susceptible to strong light entering from various sources, we conducted ray-tracing simulations to examine the optimal shapes of optical and mechanical components and determine their placement.

6) Telephoto Lens Customization Capability

On the wide-angle side, an FOV exceeding 180° is required to detect surrounding objects, whereas on the telephoto side, the required FOV varies depending on the use case. To address this, the camera is designed such that the wide-angle configuration remains unchanged, while customization is enabled by replacing the entire set of lenses on the sensor side of the beam splitter for the telephoto path. This enables the FOV on the telephoto side to be changed at low cost, and we have actually conducted development and evaluation using multiple types of telephoto lenses.

Based on these six points, we have achieved an optical design optimized for in-vehicle cameras.

It is difficult to imagine how the images will appear when the camera is mounted on a vehicle without actually seeing them. By conducting real-image simulations of the camera mounted on a vehicle from the initial design stage, we examined optimal camera specifications suited to the intended use cases. In addition, real-image simulations make it possible to conduct various verifications without producing prototypes (Fig. 4).

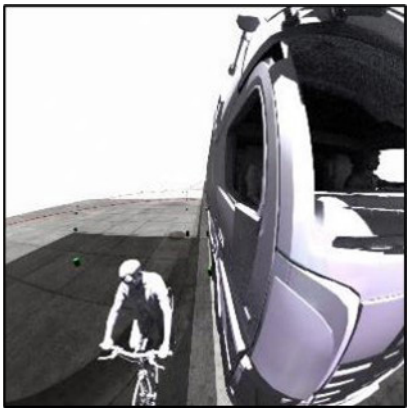


Fig. 4 Image obtained from real-world simulation

Using the developed camera, we conducted a comparative evaluation by photographing a STOP sign placed 150m away with both the wide-angle and telephoto lenses. When the sign portion of the image captured with the wide-angle lens was digitally zoomed in, the letters “STOP” appeared blurred and unreadable; however, in the image captured with the telephoto lens, the letters “STOP” were clear and could be distinctly recognized (Fig. 5).

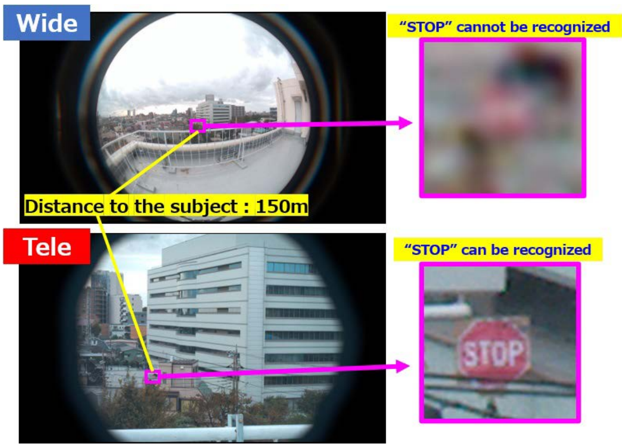


Fig. 5 Real-world image captured with the Tele & Wide coaxial camera

3 Tele & Wide Image Composition Processing

We developed image processing technology for a camera that integrates a wide-angle lens and telephoto lens. This technology is designed to provide the driver with highly visible images by combining the wide FOV of the wide-angle image with the detailed information of the distant scene captured by the telephoto image. We implemented distortion correction for the wide-angle image, composition of the telephoto image, and a digital mirror display that allows the driver to adjust the FOV, Roll (horizontal rotation), Pitch (vertical rotation), and Yaw (horizontal direction) (Figs. 6 and 7).

While the wide-angle lens offers a wide FOV, it produces characteristic image distortion. To accurately correct this distortion, we mathematically modeled the characteristics of wide-angle lenses, including fisheye lenses, using Scaramuzza's model [1]–[3]. This model represents the projection of a wide-angle lens and the distortion in its image as polynomial functions. Using this model, parameters are calculated (calibrated) based on feature points obtained from projecting a checkerboard. By applying the obtained parameters to correct distortion in the wide-angle image, straightness is restored, allowing the driver to perceive information in a visually natural manner.

Because it is difficult to discern detailed information at long distances using only the wide-angle image, the telephoto image was composited onto the wide-angle image. In principle, because the wide-angle and telephoto lenses are aligned on the same optical axis and no parallax occurs, aligning the two images is straightforward. However, to compensate for manufacturing tolerances, it is necessary to perform precise alignment for each unit using an optimal-homography matrix. This made it possible to reliably integrate the wide FOV of the wide-angle image with the detailed information from the telephoto image.

In the digital mirror display, a projection transformation matrix is calculated from the FOV, Roll, Pitch, and Yaw parameters set by the driver, enabling real-time conversion of the distortion-corrected wide-angle and telephoto composite image to any desired viewpoint. When the FOV is set wide, the broad view of the wide-angle image is displayed, and when it is set narrow, the detailed information from the telephoto image is displayed, allowing the driver to obtain optimal information according to the situation.

In addition to the aforementioned alignment, the composition of the wide-angle and telephoto images requires that the exposure timing of both images match and their brightness and color tone be consistent. If these differ significantly between the two images, unnatural discontinuities may appear at the boundary between the wide-angle and telephoto images, even when they have been precisely aligned. To address this issue, our camera system incorporates a mechanism that enables coordinated operation between the image sensors and image processing on the wide-angle and telephoto sides. First, the vertical synchronous (Vsync) signals of the two sensors are synchronized to match their exposure timing, thereby eliminating temporal misalignment.

Fig. 6 Example of digital mirror operation (left: FOV = 90°, right: FOV = 40°)

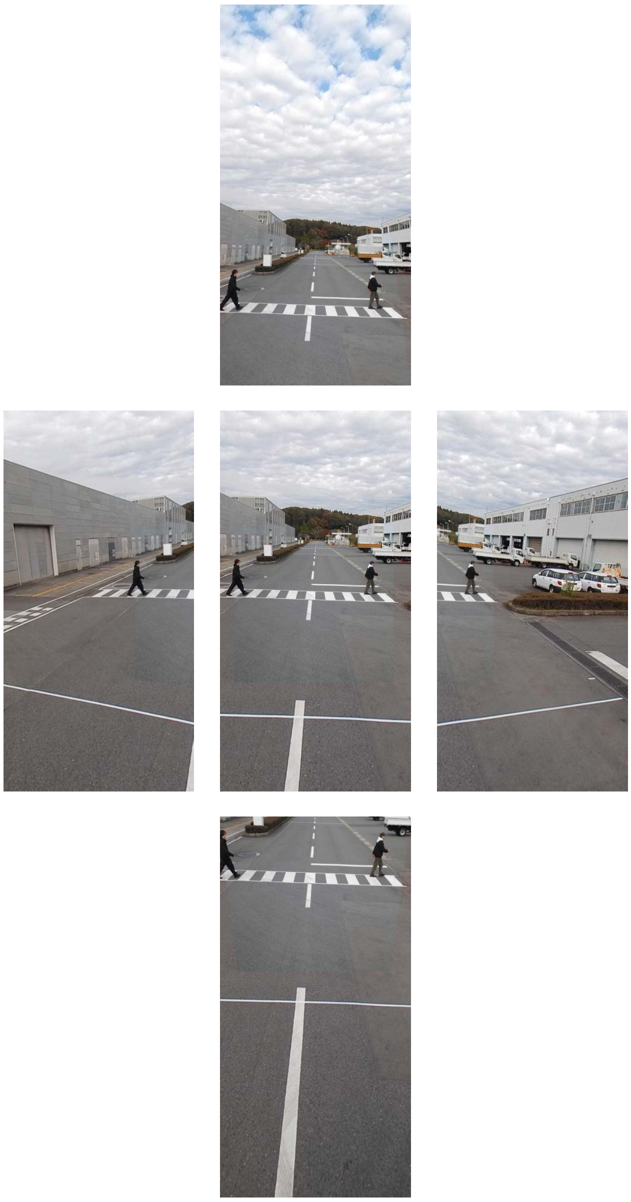


Fig. 7 Example of digital mirror Pitch and Yaw operation (center: Pitch and Yaw = 0°, top/bottom/left/right: Pitch or Yaw varied by 25° in each respective direction)

Next, luminance and color information are calculated from the exposure data of each sensor, and after coordinating the image processing, the two sensors are controlled again to match the brightness and color tone of the wide-angle and telephoto images. Figure 8 shows the composite results of the wide-angle and telephoto images with coordinated operation turned ON and OFF (the area inside the dashed line is the telephoto image). It was confirmed that the coordinated operation of the image sensors and image processing implemented in this camera system is effective in eliminating temporal misalignment and boundary discontinuities.

Coordinated operation ON / Coordinated operation OFF

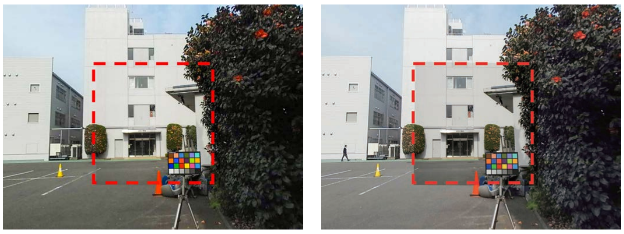


Fig. 8　Composite of wide-angle and telephoto images (coordinated operation ON/OFF: area inside the dashed line is the telephoto image)

4 Near-Infrared Compatibility

To enable shooting during both day and night, a filter that transmits only visible and near-infrared light (a multi-bandpass filter) is used. In general, the focal positions for visible and near-infrared light differ; therefore, if the sensor is positioned to focus on visible light, the focus will shift for near-infrared light. As a result, even if image quality is good for daytime shooting, it deteriorates during nighttime shooting. To mitigate this effect, the optical design incorporates axial chromatic aberration correction to minimize changes in focal position, thereby reducing image quality differences between daytime and nighttime shooting.

The advantage of near-infrared imaging with in-vehicle cameras is that it enables the acquisition of bright images, even at night in areas where light does not reach, such as in the shadows of vehicles or structures, without the need for additional visible illumination, thereby improving image recognition around the vehicle and enhancing safety. In addition, visible illumination can appear glaring to humans and may cause discomfort or impair visibility for pedestrians and drivers of surrounding vehicles, whereas near-infrared illumination does not adversely affect the vision of others and can further enhance their safety. Furthermore, because this camera system achieves near-infrared imaging using a multi-bandpass filter, it does not require switching between optical filters for visible and near-infrared light depending on bright or dark environments, eliminating the need for a filter drive mechanism and filter storage space, thereby contributing to camera miniaturization and cost reduction. Figure 9 shows the imaging results of this camera system and a conventional camera under dark conditions using near-infrared illumination.

This camera system / Conventional camera

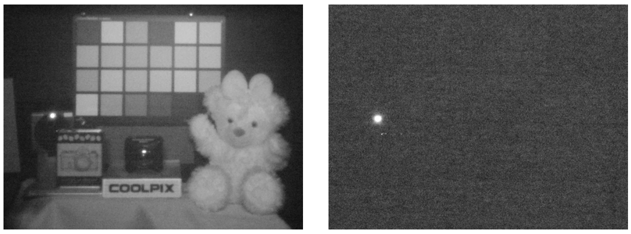


Fig. 9　Image comparison in a dark environment (illuminance: approx. 0.05 lux)
(with near-infrared illumination)

Meanwhile, because this camera system captures light containing a greater proportion of near-infrared components than conventional cameras (designed for visible light), maintaining conventional image processing results in images that appear visually poor to humans and reduce visibility. One of the intended applications of this camera system is an in-vehicle digital mirror, for which images must be rendered in a manner that humans can perceive naturally without discomfort. To address this issue, we optimized the multi-bandpass filter as well as the image processing, thereby achieving image quality comparable to that of conventional cameras, as shown in Fig. 10.

This camera system / Conventional camera

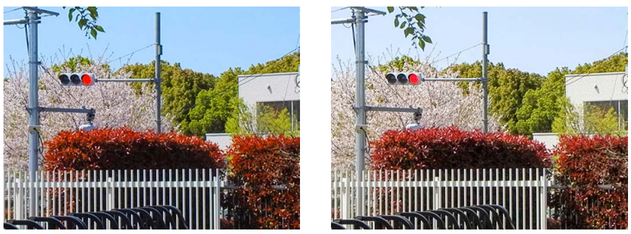


Fig. 10　Image comparison under daytime conditions

5 Other Considerations

The body of this unit employs a robust yet lightweight aluminum alloy and features a weather-resistant surface treatment, along with a sealed design with dustproof and waterproof protection applied to each component.

The shape was designed with mounting surfaces on the top, bottom, and sides to allow for various installation configurations, with a focus on robustness; however, because the wide-angle side provides an ultra-wide FOV of 190°, minimizing the body size was an essential requirement to prevent the camera itself from appearing within the FOV.

In general camera development processes, the design of the lens unit—which requires a long development period—typically takes precedence, and the body is then designed to match it; however, this often leads to restrictions on the body shape. In particular, this unit required a more efficient body design, as it needed to accommodate a specially shaped lens unit with two image sensors arranged orthogonally, along with the interface boards for each sensor.

Therefore, in this unit, the lens unit and body were designed concurrently, with design information fed back between them to optimize their respective forms, and by leveraging high-density design expertise cultivated through the development of consumer cameras—where stringent miniaturization is required—we realized a body design that does not interfere with the ultra-wide FOV (Fig. 11).

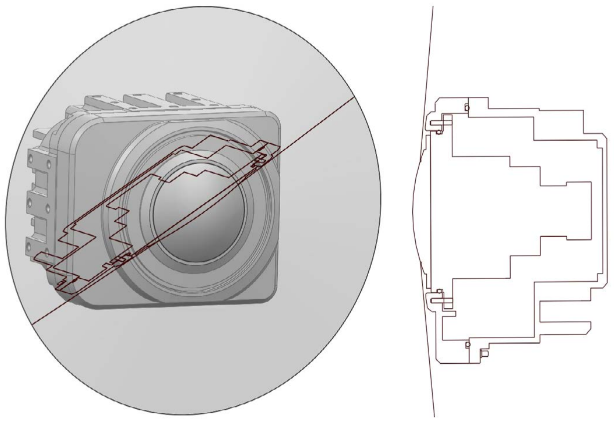


Fig. 11　Body design of the Tele & Wide coaxial camera

As mentioned above, although the focus position has been adjusted to account for reduced visibility caused by scratches or contamination, repair of the front lens may still be required depending on the extent of the damage. Regarding the repair method, the entire camera is often replaced with a new unit or disassembled to replace only the affected component; however, such approaches increase costs as well as the lead time and labor required for repair.

Therefore, in this unit, only the front lens was modularized to allow users to replace it themselves without the need for disassembling the body, thereby reducing repair costs and shortening lead time (Fig. 12). The replacement unit itself is also designed to ensure waterproofness, and its design maintains imaging performance even after replacement.

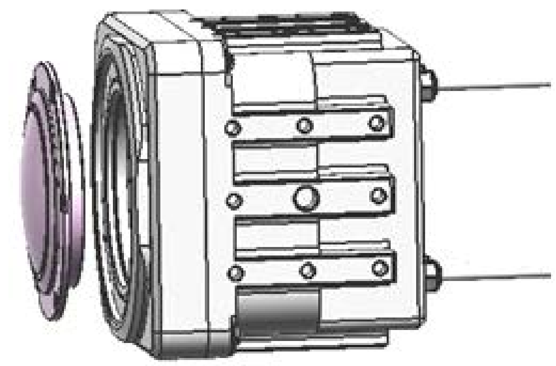


Fig. 12　Front lens replacement image

6 Conclusion

By contributing to advancing the driver-assistance systems and autonomous driving in the future automotive industry, Nikon aims to make broad contributions to society. These include reducing traffic accidents and improving safety, saving time and fuel and lowering CO_2 emissions through alleviation of traffic congestion, as well as enhancing delivery efficiency and addressing driver shortages in the logistics industry.

Finally, we would like to take this opportunity to express our sincere gratitude to the many individuals who devoted their efforts to the planning and development of this product.

References

[1] D. Scaramuzza, A. Martinelli, and R. Siegwart, “A Flexible Technique for Accurate Omnidirectional Camera Calibration and Structure from Motion,” *IEEE International Conference on Computer Vision Systems* (*ICVS 2006*), pp. 45–45, 2006.

[2] D. Scaramuzza, A. Martinelli, and R. Siegwart, “A Toolbox for Easily Calibrating Omnidirectional Cameras”, *IEEE/RSJ International Conference on Intelligent Robots and Systems* (*IROS 2006*), pp. 5695–5701, 2006.

[3] D. Scaramuzza, “Omnidirectional Vision: from Calibration to Robot Motion Estimation,” *PhD thesis, ETH Zurich, Thesis no. 17635*, 2008.

金岡浩史　Hiroshi KANAOKA
映像ソリューション推進室
Imaging Solution Development Department

倉茂孝道　Takamichi KURASHIGE
光学本部 開発戦略部
Strategic Technology Development Department
Optical Engineering

髙梨祐介　Yusuke TAKANASHI
株式会社ニコンシステム
Nikon systems Inc.

目黒明彦　Akihiko MEGURO
映像ソリューション推進室
Imaging Solution Development Department

築山大亮　Daisuke TSUKIYAMA
映像ソリューション推進室
Imaging Solution Development Department

和湯瑞葵　Mizuki WAYU
光学本部 シナジー推進部
Technical Synergy Promotion Department
Optical Engineering

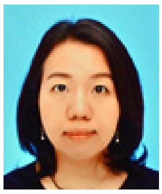

金岡浩史
Hiroshi KANAOKA


倉茂孝道
Takamichi KURASHIGE


髙梨祐介
Yusuke TAKANASHI


目黒明彦
Akihiko MEGURO


築山大亮
Daisuke TSUKIYAMA


和湯瑞葵
Mizuki WAYU