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The Advanced Technologies for “Safe Society”

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ADVANCE

The Advanced Technologies for "Safe Society"

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Technical Reports

Precis

In recent years, as part of international cooperation activities, the Japanese government has been promoting proposals for the export of disaster prevention technology & products to other countries. In response to such governmental activities, Mitsubishi Electric is strongly pursuing a broader operational presence for our disaster prevention products around the world.

Exploiting such strengths as cutting-edge technologies for satellite communications, radar, and the electronic devices of the IT Space Solution Division, Mitsubishi Electric will continue to help build a safer society by introducing products in the fields of safety, security, and disaster prevention to countries worldwide.

Overview

Author: *Shoichi Kimoto**

Global business development of the advanced technologies for “Safe Society”

Mitsubishi Electric is building a safer society by introducing diverse products employing cutting-edge technologies, including sensors, radar and other electronic devices, developed in our defense and space businesses. This issue starts with Mobile Mapping Systems (MMS). Equipped with antennas that receive position information from GPS satellites, inertial measurement units, cameras, and laser scanners, these systems are mounted on a vehicle and used to measure geographical space image data and 3D laser point group data while the vehicle is moving. Most MMSs are used for public surveying, such as in disaster prevention, for investigating changes and sinking in river banks, fine cracks in tunnel inner walls, and cracking in road surfaces. In the field of future Intelligent Transport Systems (ITS), MMSs are expected to develop into automatic driving assistance systems that use precision data from quasi-zenith satellites, including landscape information and road information. In addition, by exploiting synergies with vehicle onboard millimeter wave radar developed by Mitsubishi Electric, MMSs could help monitor safety at intersections and other traffic safety tasks.

Next, we look at Doppler Lidar, a device that emits a laser beam, receives light reflected from atmospheric aerosols (dust, particles), and determines the wind velocity based on its moving velocity. Doppler Lidar can be used to remotely measure the distribution of wind velocity at altitude, and is used for observing wind state and the like, such as at airports for monitoring wind shear to ensure the safety of aircraft. Mitsubishi Electric is also involved in an R&D project on aircraft onboard lidar systems to observe the turbulence that threatens aircraft safety. In environmental applications, Doppler Lidar may be useful for monitoring and forecasting wind direction in cities, related to the heat island phenomenon, air pollution, etc., as well as in the field of renewable energy to assist wind power generation by controlling wind turbines for greater operational efficiency and longer service life.

Finally, this issue looks at a next-generation scanning device known as the Deep Focus Image Sensor. Mitsubishi Electric already supplies contact image sensors as currency readers for determining the authenticity of bills, thus protecting the security of currency in circulation. Deep Focus Image Sensors are a newly-developed type of reader which aims to penetrate this market by delivering a depth of focus equivalent to conventional reducing optics devices used in copier machines. With a view towards the safety of Monozukuri, Mitsubishi Electric will develop Deep Focus Image Sensor products for applications such as inspections for scratches and chipping in semiconductor wafers and glass plates.

Mitsubishi Electric is expanding its business globally. Exploiting such strengths as cutting-edge technologies and unique products in satellite communications, radar, and electronic devices of the IT Space Solution Division, we will continue to help build a safer society by introducing products in the fields of safety, security, and disaster prevention in countries worldwide.

**Deputy General Manager, IT Space Solution Division*

The Latest Trends in Mobile Mapping System

Authors: *Mitsunobu Yoshida** and *Mamoru Yoshida***

Social infrastructure, ranging from roads to bridges, harbors, tunnels, and water and sewers, is increasingly important for economic activity. However, now that a half century has passed since Japan's high growth period during the 1950s and 60s, maintenance and repair have become major issues. Many facilities now require attention, and so technologies for ensuring efficient management of maintenance are essential. Mobile Mapping System (MMS) are one such key technology.

An MMS precisely and efficiently measures 3D map data of the surroundings of a moving vehicle using GPS and various other sensors mounted on the vehicle.

Mitsubishi Electric is developing customized MMS for various applications, including moving measurement of road registers, tunnel linings, waterways, underground areas, and three-dimensional cityscapes and wide areas (Fig. 1).

We are now studying expanding the application of MMS to railway and road surface inspections. Meanwhile, multiple satellite positioning systems (Global Navigation Satellite Systems, or Multi-GNSS) such as GPS, GLONASS, GALILEO, and GAGAN are being put into space and will be used as positioning satellites. Japan also has already launched its first quasi-zenith satellite, called Michibiki, and has started positioning signal development. An additional three satellites are to be launched to create a four-satellite system. Accordingly, we are rapidly developing technologies for effectively using these satellites to contribute to society in the areas of protection against disasters, maintenance management, safety management, and other such missions.

1. Outline of MMS

1.1 Basic configuration and functions

The definition of MMS generally includes the following two points:

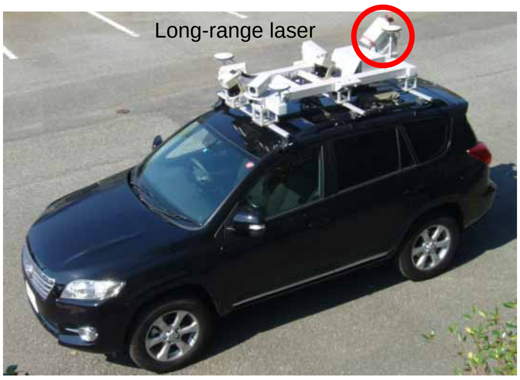
(1) A system mounted on a vehicle, including a positioning device such as GPS and a measurement device such as a camera or laser scanner.

(2) Capable of capturing 3D shapes of the surroundings of a vehicle that is traveling on a road.

Its basic function is to calculate the self-position and attitude of a vehicle using a combination of one to three GPS antenna/receiver units, an inertial measurement unit (IMU), and an odometer that detects tire rpm. In addition, a 3D coordinate system is simultaneously applied to the measurement data obtained by a vehicle-mounted camera or laser system.

1.2 GPS/IMU/Odometer combined calculation

An MMS identifies position by GPS positioning calculation and attitude by GPS gyro with three GPSs. Combined positioning calculation is also carried out with multiple sensors to which an odometer (tire rotation indicator) has been added in addition to the IMU.



MMS-X320R
(Long-range laser mounted on vehicle enables remote measurement over distances of up to 200 m)

MMS-K
(Improved type standard model; shown in photo with omnidirectional camera mounted)

Fig. 1 MMS variations by Mitsubishi Electric

**Kamakura Works   ***Ryoden Shonan Electronics Corporation*

GPS/IMU/odometer combined calculation has two purposes: (1) accurate positioning through mutual compensation of the effects of noise included in the position calculation of the GPS itself, the effects of the integration error component contained in the position calculation of the IMU, and the scale factor error contained in the distance calculation of the odometer, and (2) positioning of locations where GPS signals cannot be received.

Though positioning by GPS does not have a time accumulation component in its error, each measurement does contain an error. On the other hand, IMU data has little error over short times, but errors do accumulate with the passage of time. Additionally, while the odometer obtains distance traveled using tire rpm, the distance traveled per revolution fluctuates in accordance with such factors as temperature, air pressure, and number of vehicle passengers. Mitsubishi Electric's MMS merges these three types of positioning systems into a tightly-coupled system that performs batch position and attitude calculations. With the effective use of GPS positioning, position in the world coordinate can be acquired without using local origin.

1.3 Usability

Mitsubishi Electric's MMS is designed to be operated without requiring specialist knowledge; anyone should be able to operate the vehicle and use the software that performs the post-processing. The post-processing software is designed to automatically compute up to the color laser point cloud that employ camera images without the user having to perform complicated procedures, even in the case of multiple measurements by multiple vehicles.

However, as moving body measurement using vehicles is entering general use and demand is rising, MMS needs to be made easier to use.

Accordingly, the MMS-K, our latest model (Fig. 1, right), improves on the existing model with upgraded performance and ease of use. It has the following six features.

(1) Improved operator's communication with the driver by enabling operation from the passenger seat.
(2) The odometer is placed inside the vehicle wheel and a non-contact system is used, eliminating the need for overfenders and avoiding breakdowns due to collision with the odometer.
(3) By mounting a new type of standard laser, we almost doubled both the number of arrival distance and acquisition points. In addition, the system can obtain reflection brightness, enabling laser measurement unaffected by sunlight.
(4) The system can now be mounted on compact cars, and thus used for measurement on narrower roads.
(5) The recording media is solid-state, preventing recording omissions caused by vibration or impact.
(6) By integrating the in-vehicle recording units and placing them in the rear of the vehicle, the riding capacity of the vehicle is increased.

2. Examples of MMS Use

Here we describe the following examples of application according to the type of mounted sensor.

- Road register and other public surveying: standard unit
- 3D landscapes, etc.: Long-range laser
- Waterway measurements, etc.: Omnidirectional camera

2.1 Public surveying, such as road registers

As indicated by its name, MMS has been developed for producing maps and is frequently used for creating the maps that are included in road registers and water supply and sewer registers. In addition to efficient measurement, the acquired 3D data also enables other maintenance management operations to be performed, including improvements to intersections and checking for protruding signs and trees. Because roads and water supply and sewers are managed by national and local government bodies, surveys must be conducted as public surveys. Regarding the above-mentioned surveying employing Mitsubishi Electric's MMS, over 50 local governments have applied for Provision 17 of the public survey work regulations of the Ministry of Land, Infrastructure, Transport and Tourism, and have been approved by the Geographical Survey Institute. Figure 2 shows an example of a point cloud acquired by the MMS-K. A point cloud has a coordinate for each single point and is used to identify positions and measure distances and shapes. The MMS is capable of measuring position, distance, and other parameters using point cloud and checking target objects using camera images.

2.2 Landscapes (example of use of long-range laser)

We developed an MMS mounted with a long-range laser that can measure at distances of over 200 m

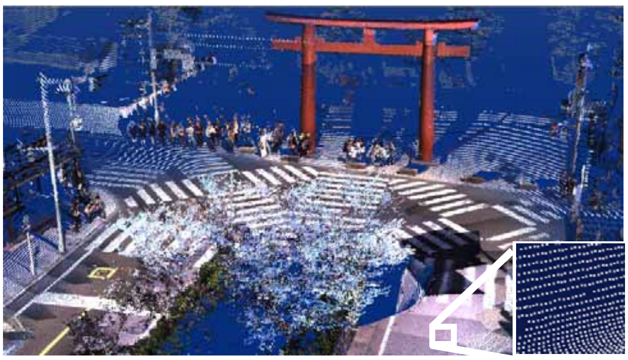


Fig. 2 Point cloud from MMS-K
(The partially enlarged area at the bottom right shows how the image consists of a collection of points.)

(Fig. 1, left). Figure 3 shows a measurement example that can distinctly measure rooftop areas of groups of high-rise buildings over 150 m in height. This system enables identification of up to building groups in register map areas, and is also used for landscape surveying and 3D city modeling. The system is also useful for maintenance management of cliffs and waterways where it can be used to check the safety of cliff faces by measuring their inclination, and can ascertain the current state of the opposite banks of waterways.

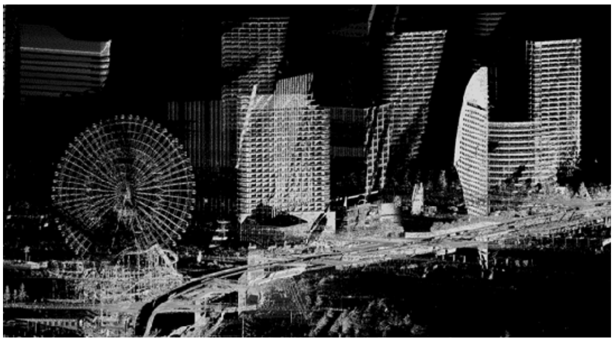


Fig. 3 Measurement results of long-range laser

2.3 Waterway measurements (example of use of omnidirectional camera)

The camera of MMS is used mainly to visually check the condition along roads, but because of emerging demand for checking the condition of not only road areas but also the entire surroundings, the system has been designed to be mounted with a camera that can simultaneously capture all directions (Fig. 1, right). This camera integrates five cameras into one and can thus obtain a seamless 360° image in one shot. Figure 4 shows an example of such a shot. The left side of the image shows the forward direction, the right side the rear direction, and the middle the right side. The MMS unit appears at bottom. The top shows how the camera captured an elevated highway that parallels the road. The combination of this image and MMS standard camera image can accurately grasp the conditions in all directions. This camera is used in a number of applications for measuring the current state of waterways.

Fig. 4 Example of omnidirectional camera shot

3 Prospects for Development

3.1 Railways

Like roads, railways, track areas, and tunnels also require maintenance management. At present, trials are under way in which MMS are mounted on trolleys, etc. and used for railway measurements. By measuring the 3D shapes of track areas, the system could be used for analyzing rolling stock, gauge and track clearance as well as for checking the integrity of tunnels. Such measurements could also be used as fundamental data for future railway ITS.

However, because railway rails do not allow road-like travel in which there are free route changes and GPS compensation, the measurement devices and post-processing of measurement data require special techniques. Also, though application to subways as continuous tunnels is also possible, the lack of GPS reception over entire lines means further system studies are necessary.

3.2 Road surface properties

Road surface properties are indexes indicating the integrity of paved road surfaces. High-precision lasers could be used for surveying such properties. If measurements can be easily carried out with fixed precision using MMS and in compliance with the Pavement Survey and Test Method Handbook, then the system could be used for measurements for road maintenance management. In addition, if the measurement results can be expressed by aligning them positionally over the road register, then road management drawings could be produced that are easy for managers to use.

The “Crack” category is a key item when surveying road surface properties. Cracks of 1 mm or greater must be detected and captured by camera, but current standard cameras do not have sufficient resolution, suggesting that cameras dedicated to paved surfaces are needed.

4. Conclusion

This article has discussed the current state and future prospects of the management of various types of infrastructure using MMS. 3D technologies are likely to be widely used in the future. Further work is needed not only to enhance the efficiency of measurement travel and its subsequent point cloud generation, but also for automatic processing of measurement data for enhancing the efficiency of the overall process up to creating 3D maps and social foundation data.

For example, current topological coordinates registered as initial values in a database and ordinarily used for temporal aging tracking in maintenance management can be rapidly used for damage surveys and recovery planning following a disaster.

By spreading use of MMS, 3D measurement can now accumulate, with high precision and efficiency, initial data for temporal aging and for future applications. Such data will be invaluable for engineers and managers performing maintenance management of social infrastructure and devising measures in case of emergency, such as during earthquakes and other disasters.

We will continue to contribute to society through the development of MMS and its applications.

Performance Evaluation of Laser Measurements by Mobile Mapping System

Authors: *Yoshihiro Shima** and *Kenji Togashi**

Mobile Mapping System (MMS) comprises GPS and other types of sensors mounted on a vehicle to perform 3D measurement of the surroundings while the vehicle is traveling. Since they can easily measure the planimetric features of road areas, they are used for producing road area maps for example, and are also included in the public survey operation manual proposal.

As the use of MMS spreads, they are being used for collecting data in various environments in a broader range of applications, leading to demand for more detailed measurements across a wider range beyond previously-supported road areas. Now that half a century has passed since the construction of many roads, railways, and other domestic transportation infrastructure, there is growing demand for using MMS to conduct detailed measurements of 3D shapes around a moving vehicle in order to assess the current situation for the purpose of maintenance management.

In response, Mitsubishi Electric has added an MMS mounted with a long-range laser scanner to its current lineup of standard laser scanners (Fig. 1). We have also developed measurement vehicles mounted with high-precision laser scanners for detailed measurement of tunnel walls and road surface properties, and are now making these laser scanners available as an MMS option.

This article presents the results of evaluating and verifying the precision of 3D data obtained using an MMS mounted with these high-performance laser scanners.

1. Outline of MMS

1.1 What is MMS?

MMS comprises devices for the following functions:

(1) Measurement of automobile position and attitude
(2) Measurement of the planimetric features of vehicle surroundings

GPS antennas and receivers, an inertial navigation system, and an odometer for measuring tire rpm are mounted on a vehicle to serve as sensors for function (1). This sensor combination measures vehicle position and attitude. A camera and laser scanner are mounted as sensors for function (2).

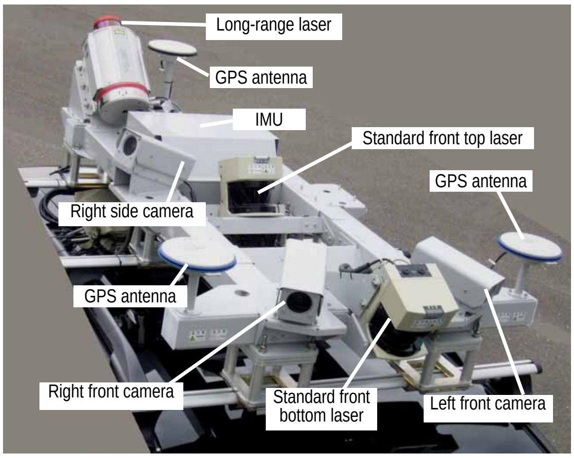


Fig. 1 Mitsubishi Electric Mobile Mapping System MMS-X320R
Left: external appearance of system, above right: external appearance of equipment mounted on rooftop, bottom right: external appearance of odometer

*Kamakura Works

1.2 Types of MMS-mounted laser scanners and their applications

Table 1 shows types of laser scanners mounted on an MMS and their respective applications.

Table 1 Laser scanner types and main applications

Laser scanner type	Main applications
Standard	・Road register and other public surveying ・Current road condition surveys
Long-range	・Cityscape measurement ・Erosion control measurement ・Inclination measurement
High precision	・Tunnel measurement ・Road surface properties measurement ・Electric wire and telephone pole measurement

2. Evaluation of Laser Measurement Performance

2.1 Laser scanner stand-alone specifications

Table 2 shows the main stand-alone performance specifications (catalogue values) of long-range, high-precision, and standard lasers.

As shown in Table 2, the long-range laser can measure at distances of up to 200 m. It also provides 3,000 laser points per scan in the direction perpendicular to the road. A long-range laser possesses the advantage that, because it can measure reflected waves from multiple distances with a single pulse, even if measurement targets are hidden by plant branches and leaves, as long as a part of the laser spot penetrates, the shapes beyond can be measured.

In contrast, high-precision lasers have a measurement accuracy of 0.56 mm, making them suitable for measuring range directions requiring high resolution. With a number of laser points of about 10,000 points per scan (at 100 Hz), the high-precision laser is more precise than the long-range scanner.

Moreover, all laser scanners, including the standard laser scanner, are capable of acquiring intensity information.

2.2 Comparison of standard and long-range laser scanners

Figure 2 shows cross-sectional plots of a road in the transverse direction obtained using standard and long-range scanners to measure the shape of curb next to the lane traveled by vehicles. The plot has been purposely shifted to prevent overlapping. This graph shows clearly that the point cloud from the long-range scanner was more dense than the point cloud obtained by the standard laser.

Figure 3 shows plots of the cross section along the road’s longitudinal direction (direction of vehicle travel) obtained by using standard and long-range scanners to measure the shape of curb next to lane traveled by vehicles. As shown in Fig. 3, the points are shown shifted to prevent overlap. The laser point cloud density in the road’s longitudinal direction is determined by the scan speed, and, because both the standard and long-range scanners scan at 100 Hz, there is no difference between them. Measurement values of the grade level are also the same.

3.1 Long-range laser scanner evaluation

To evaluate the accuracy of the laser point cloud of an MMS-mounted long-range scanner, we surveyed buildings that can be seen from the road as shown in Fig. 4, and then compared the difference in results with the MMS measurement results.

Table 3 shows the conditions for long-range laser point cloud accuracy evaluation. All targets are measured with good GPS satellites visibility and without performing Ground Control Point (GCP) collection.

Figure 5 shows a plot of the standard error

Table 2 Laser scanner stand-alone performance specifications

Item	Laser scanner type			
	Long-range	High precision (1)	High precision (2)	Standard
Angular field of view (degrees)	360	310	360	190
Maximum measurement distance (m) (typical value)	200	79	119	65
Maximum pulse rate (pulses/sec)	300,000	500,000	1,000,000	28,000
Maximum scan rate (Hz)	100	100	200	100
Distance accuracy (repeatability) (mm) (typical value)	5	0.8	0.56	9
Maximum number of detection targets per pulse	5	1	1	5
Reflection signal brightness information	Yes	Yes	Yes	Yes

obtained from target measurement results to which a linear approximation line has been fitted. Figure 5 reveals that, when the distance to the target is 80 m or less, both the standard deviation and average difference for long-range scanner measurement accuracy are 0.1 m or less.

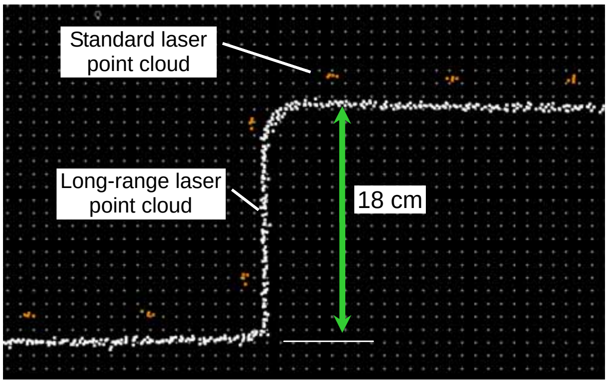


Fig. 2 Comparison of transverse direction measurement values

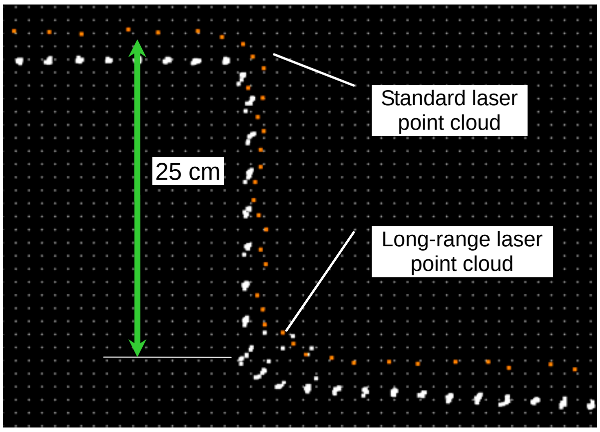


Fig. 3 Comparison of longitudinal direction measurement values

3.2 High-precision laser evaluation

3.2.1 Grade level measurement by high-precision laser

To evaluate the grade level measurement resolution for tunnel and road property measurements using high-precision lasers, we measured the target

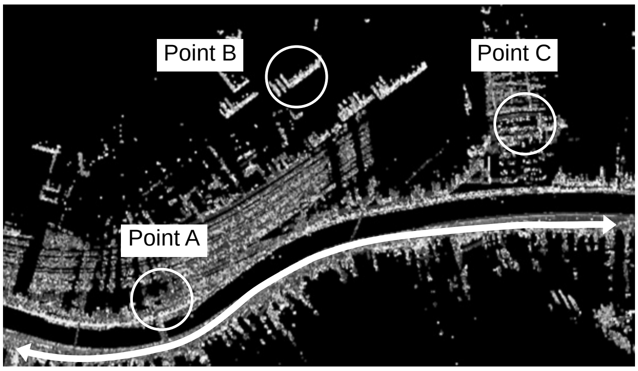


Fig. 4 Positional relationships of road traveled and targets

Table 3 Conditions for evaluating long-range laser point cloud precision

Item	Verification conditions
Travel speed	30 – 50 km/h
Number of passes	26 passes (13 round-trips)
Condition of road surface	Some bumpy areas due to construction
Satellite conditions	Good satellite visibility
Scan speed	100 Hz
Horizontal distance to target points	Point A: 60 m, Point B: 209 m, Point C: 111 m

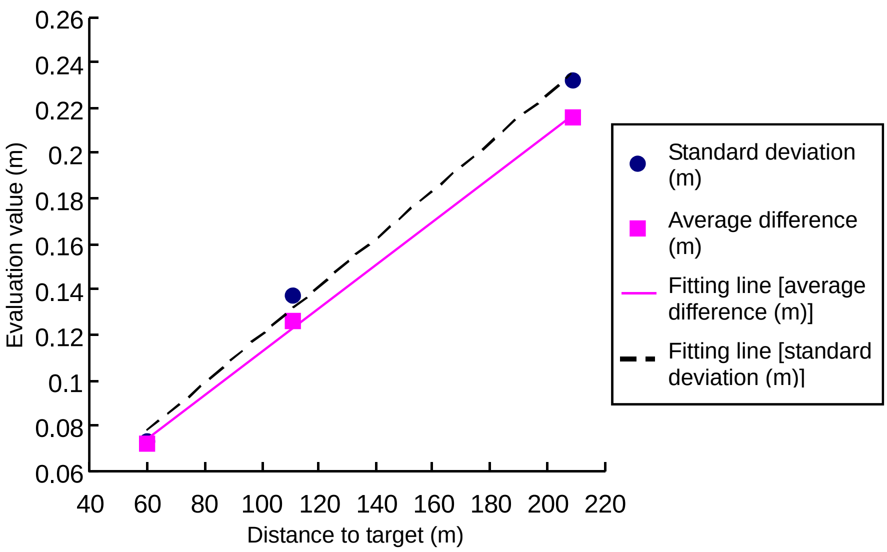


Fig. 5 Results of evaluation of long-range laser point cloud precision

plates shown in Fig. 6 and compared the measurement values with values measured by calipers.

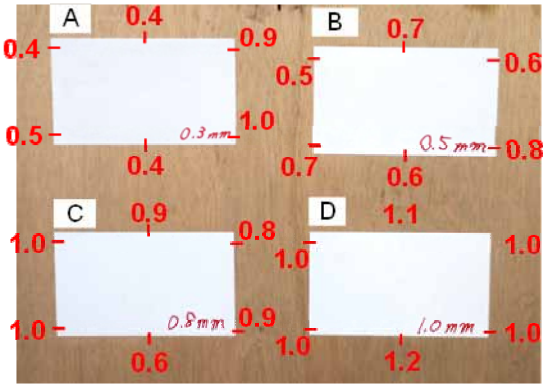


Fig. 6 Thin plate target place (values in figure are caliper measurement values)

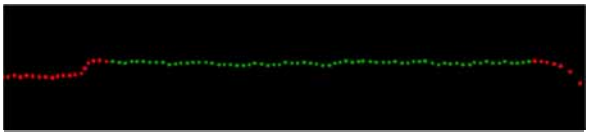
Table 4 shows the results of measurement using a high-precision laser. The results of this experiment demonstrated the feasibility of distinguishing thicknesses of about 0.2 mm using an MMS mounted with a high-precision laser.

Table 4 Results of measurement accuracy evaluation

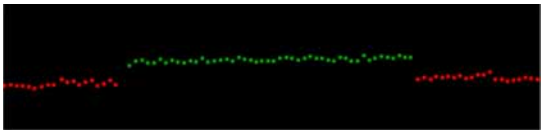
Target	MMS measurement average value	Caliper measurement average value	Difference value
A	0.647 mm	0.430 mm	+0.217 mm
B	0.708 mm	0.580 mm	+0.128 mm
C	0.762 mm	0.850 mm	-0.088 mm
D	0.927 mm	1.035 mm	-0.108 mm

3.2.2 Comparison of flatness of high-precision laser scanner and long-range laser scanner

Figure 7 shows plots of one-scan targets obtained using high-precision and long-range laser scanners to measure target plates at a distance of about 3 m. Table 5 shows the results of flatness calculation using laser groups comprising 100 points for each of the scanned targets. As shown in Table 5, the results of this experiment indicated that the high-precision laser exhibits four times less measurement discrepancy than the long-range laser.



(a) High-precision laser



(b) Long-range laser

Fig. 7 One scan data comparison of laser point cloud

Table 5 Comparison of laser point cloud flatness

	High-precision laser scanner	Long-range laser scanner
Flatness σ	0.35 mm	1.40 mm

4. Conclusion

In this article, we introduced MMS models mounted with a long-range laser and high-precision laser, which are designed to satisfy new MMS needs. We also presented the results of evaluating the measurement precision of these lasers.

By mounting a high-precision laser on an MMS, we dramatically increased the measurement range, which had been restricted to about 30 meters from the vehicle, thus enabling 3D measurement of the topography of a wide area in a single pass. This technology will boost the use of 3D data in new fields, such as for measuring slopes and 3D modeling of cityscapes.

Additionally, we hope to help improve the safety of infrastructure by improving the efficiency and frequency of inspections by using MMS mounted with high-precision lasers for surveying the conditions of tunnels, roads, and various other social infrastructure.

The measurement by a vehicle on land is expected to find wider applications in the future. We will continue to contribute to safety and confidence in society by developing not only lasers, also products adapted to needs.

Doppler Lidar

Authors: *Masayuki Enjo** and *Yoshiyuki Yabugaki**

Doppler Lidar (LIDAR: Light detection and ranging) is a system used for measuring remote wind speed: the apparatus emits laser light and receives the waves backscattered from aerosols (fine particles such as dust) suspended in the atmosphere, which reflect variations in Doppler frequency, and for which the apparatus has a detection feature. The Doppler Lidar is able to measure wind speed under fair weather because the apparatus receives the scattered wave emitted from aerosols in the atmosphere (see Fig. 1).

In 2000, Mitsubishi Electric successfully developed a Doppler Lidar system consisting of optical fiber parts. Since then, Mitsubishi Electric has commercialized fully optical fiber Doppler Lidar systems, and also developed a long-range Doppler Lidar system for measuring wind speed over a wider range. The long-range Doppler Lidar is housed inside a shelter to prevent any effects from its installation environment. Scanning at an arbitrary angle of elevation and arbitrary azimuth direction is made possible by emitting laser light via a scanner device composed of two reflecting mirrors. A compact Doppler Lidar is composed of two devices: an optical antenna that is installed on a tripod; and a main body. This is more portable than other Doppler Lidar systems.

This paper presents a compact Doppler Lidar system that Mitsubishi Electric developed for wind condition observations mainly in the wind power generation field, and gives an overview of the long-range and compact Doppler Lidar systems developed by Mitsubishi thus far.

1. Long-Range Doppler Lidar

The optical parts of the Doppler Lidar systems, which consist solely of optical fiber, provide an advantage in terms of downsizing and ease of handling. However, the observation range has been limited because the peak value of the laser optical power is limited to a few dozen watts due to the nonlinear optical effect generated within the optical fiber parts in the transmission light path. For this reason, and to expand the wind speed measurement range of the Doppler Lidar systems, we developed a laser light amplifier capable of achieving high output, which has since been put into practical use. The exterior of this long-range Doppler Lidar is shown in Fig. 2. The entire Doppler Lidar system is housed inside a shelter so that it is not affected by the installation environment. Laser light is emitted into the atmosphere by using the scanner device installed at the ceiling of the shelter. The scanner device is composed of two reflecting mirrors; by changing the angle of the mirrors, the laser light can be scanned or directed at an arbitrary angle of elevation and arbitrary azimuth direction. Figure 3 shows the scanning patterns of this Doppler Lidar system.

This type of Doppler Lidar system can measure up to approximately 20 km, and is expected to be used for weather observations and measurements of the planar distribution of wind speed in the vicinity of airports.

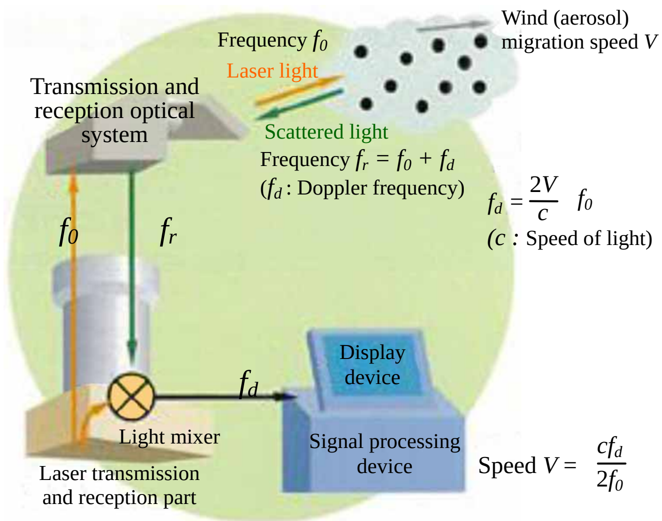


Fig. 1 Principle of Doppler Lidar wind speed measurement

**Communication Systems Center*

Fig. 2 Large-scale coherent Doppler Lidar system

In addition, applications utilizing the system's ability to measure wind speed under fair weather include the detection of vortexes called wake turbulence, which is generated from both ends of an aircraft's primary wings while in flight. Since the wake turbulence generated by an aircraft affects the aircraft flying behind it, the aircraft taking off and landing at airports must maintain a certain interval. Based on the data derived from the vertical plane observation (refer to Fig. 4) of aircraft tracks, obtained using the Doppler Lidar system, Mitsubishi Electric developed an algorithm capable of detecting wind speed patterns that are in agreement with the features of wake turbulence by correlation for a space region. Practical application of wake turbulence detection is expected to contribute to the operational safety of aircraft.

2. Compact Doppler Lidar

The compact Doppler Lidar system features smaller size and improved reliability for all of the optical fiber parts for transmitting and receiving laser light. This type of Doppler Lidar is composed of a main body that conducts oscillation, amplification and reception of laser light, and an optical antenna that emits laser light into the atmosphere and receives backscattered waves. The appearance of the compact Doppler Lidar system is shown in Fig. 5.

The optical antenna is installed on a tripod, and its portability is enhanced by making it possible to remove and install the cables and optical fibers that are connected to the main body. Furthermore, we developed a FPGA-type signal processing board for exclusive use

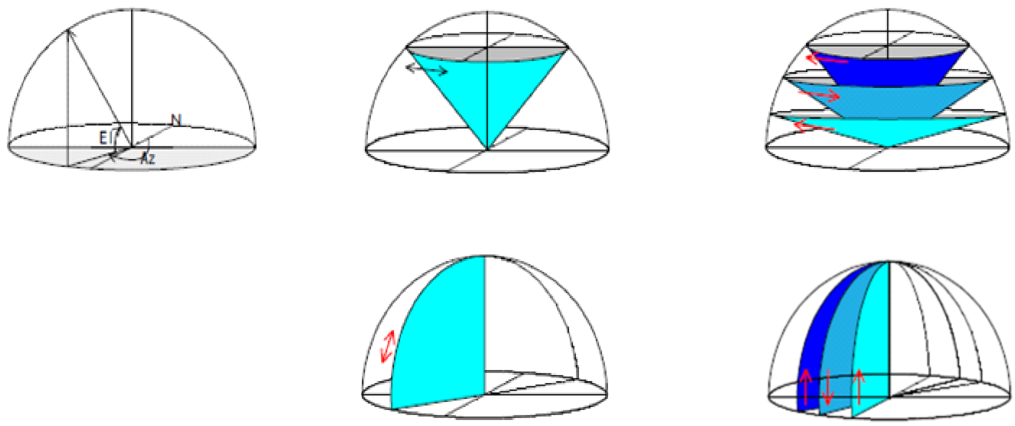


Fig. 3 Scanning pattern of the long-range Doppler Lidar system

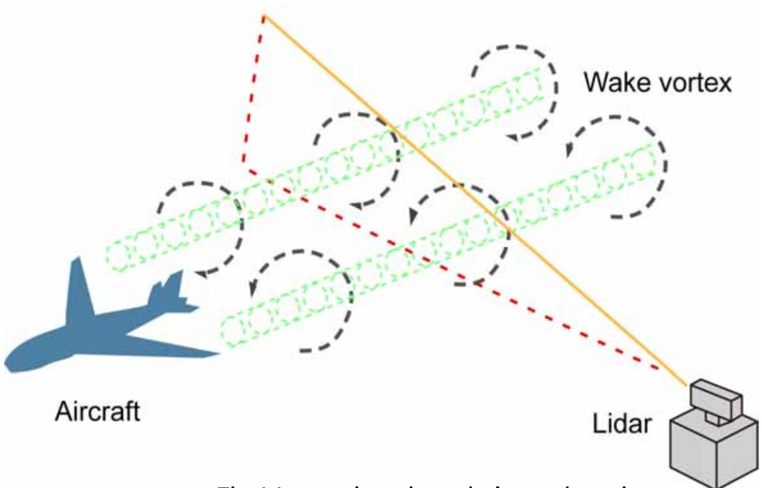


Fig.4 Layout in wake turbulence detection

Fig. 5 Compact optical-fiber Doppler Lidar system

with the compact type Doppler Lidar, which allows us to carry out signal processing to display the processed data in real time, thereby enhancing its usability.

The compact Doppler Lidar system, driving the optical antenna independently in the horizontal and vertical directions, can conduct conical, horizontal and vertical scanning. Figure 6 shows the scanning patterns of this Doppler Lidar.

3. Doppler Lidar Developed for Wind Power Generation

The feed-in-tariff scheme was introduced in July 2012 to encourage power generation by renewable energies. Wind power generation is expected to be greatly increased as one of the options, and its development has spread throughout the world as a promising renewable energy. In order to contribute to this industry, we developed a compact Doppler Lidar system for observing wind conditions mainly related to wind power generation.

In this application, wind direction and wind speed are measured in order to predict the amount of power generation and compare the actual amounts of generation with the predicted. To do this, it is necessary to obtain the values at a height near the rotation axis (hub) of a wind turbine: it is impossible to conduct such measurements without installing a mast with a vane anemometer near the hub. In addition, the hub position becomes higher as the diameter of wind turbines increases, so the mast too must be raised higher. This increases the cost of mast installation, maintenance and management. As the Doppler Lidar system can measure wind direction and wind speed at a height in the vicinity of the hub, we developed the compact Doppler Lidar system for observing wind conditions. Figure 7 shows the concept of measurement and Figure 8 shows the appearance of the developed product. This compact Doppler Lidar can measure the wind direction and wind speed in the horizontal

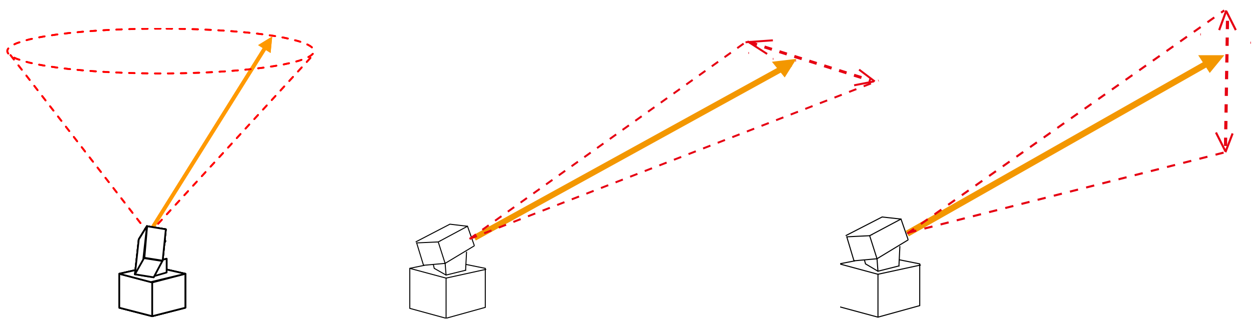


Fig.6 Scanning patterns of compact Doppler Lidar system

Fig.7 Rendition of Lidar in the field

Fig. 8 Compact Lidar system for wind condition observation

direction and the wind speed in the vertical direction up to a height of 40–250 m with a range resolution of 20 m.

4. Conclusion

The development of Mitsubishi Electric's Doppler Lidar systems was described. Efforts have been made to commercialize the long-range type and compact type Doppler Lidar systems, which are expected to be useful in various fields including weather and environmental measurements, and aircraft operation and control. Mitsubishi Electric will continue to develop Doppler Lidar systems to expand the fields of application including wind power generation.

Deep Field Image Sensor (DeFIS)

Authors: *Tatsuya Kunieda** and *Hiroyuki Kawano***

Mitsubishi Electric is developing and manufacturing a contact image sensor (CIS), which is used for reading the reverse side of documents in the auto document feeder (ADF) of copying machines and similar equipment. As CISs are compact and produce high-resolution images, they have been installed in many copying machines. However, the depth of field (DOF) of the CIS imaging system is shallow, and therefore a high-resolution image can only be obtained by scanning in close contact with the imaging object, making it impossible to apply CIS scanning from the platen side (front surface reading) of a copying machine.

A deep field image sensor (DeFIS) is a new reading device developed for flatbed scanner of copying machines through the elimination of the shallow DOF in conventional CISs. With the combined use of multiple reflective telecentric imaging systems developed by Mitsubishi Electric, DOF comparable to that of a conventional flatbed scanner device called optical reduction system of conventional copying machines is achieved, thus reducing the size and weight of the DeFIS close to CIS.

This paper describes the composition of the DeFIS (see Fig. 1), the features of each part and the element technologies supporting these features.

Note) Telecentric optical system: This is an optical system in which the principal rays are vertically incident on the surface of the imaging object, and no change in magnification is caused by any change in the distance to the imaging object.

1. Outline of the Device

1.1 Composition

The basic composition of the DeFIS (see Fig. 2) consists of the following systems and components as with CISs: (1) an illumination system that lights up the

Fig. 1 Appearance of the deep field image sensor (DeFIS) and an example of obtained pictures of an imaging object with concavity and convexity

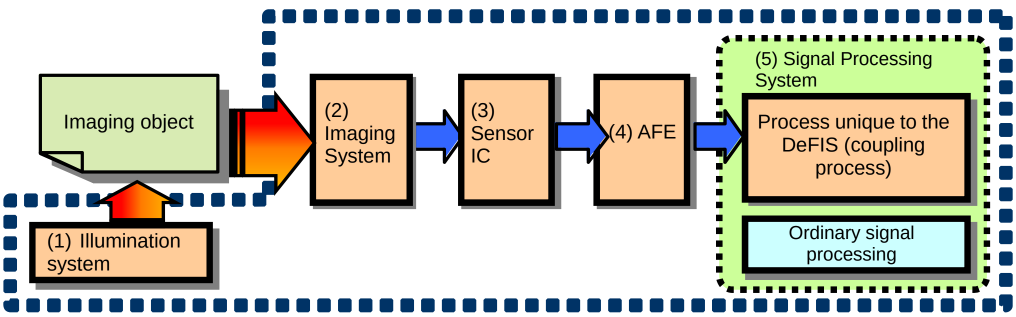


Fig. 2 Device composition

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imaging object; (2) an imaging system that forms optical images from the information of the imaging object; (3) a sensor IC that converts the formed image information into electric signals; (4) an analog front end (AFE) that is used for digital conversion of the analog output from the sensor IC; and (5) a signal processing system that outputs to the clients' systems the digitized image information after signal processing. Among these systems and components, those that differ substantially from CIS are (2) the imaging system and (5) the signal processing system.

1.2 Features

The features of the DeFIS related to usage of the device as a copying machine are as follows.

(1) Deep field

DOF of 4 mm has been achieved thanks to a newly developed imaging system, and the image does not rapidly deteriorate as the imaging object is moved farther away, resulting in a naturally blurred impression (see Fig. 3). Since DOF holds a trade-off relationship with the degree of brightness of an imaging system, if DOF required for practical use is set at 2 mm, it is possible to create a brighter imaging system and to reduce the power consumption of the illumination system.

(2) Longer distance from the imaging object

Figure 4 shows a cross-section structural drawing of the DeFIS. The newly developed imaging system allows a large distance between the device and the imaging object.

(3) Less image distortion

Due to the telecentric optical system employed in the imaging system, the size of the image to be read does not change as the distance to the imaging object changes (see Fig. 5).

(4) No missing pixels

The conventional CIS uses multiple sensor IC chips in one line, which entailed one missing pixel per sensor chip because a gap was needed at every joint between the sensor chips. In the DeFIS, the adjacent sensor ICs are arranged in a staggered shape, so these sensor ICs read in an overlapping manner and obtain an image without any missing pixels.

(5) Compact and lightweight

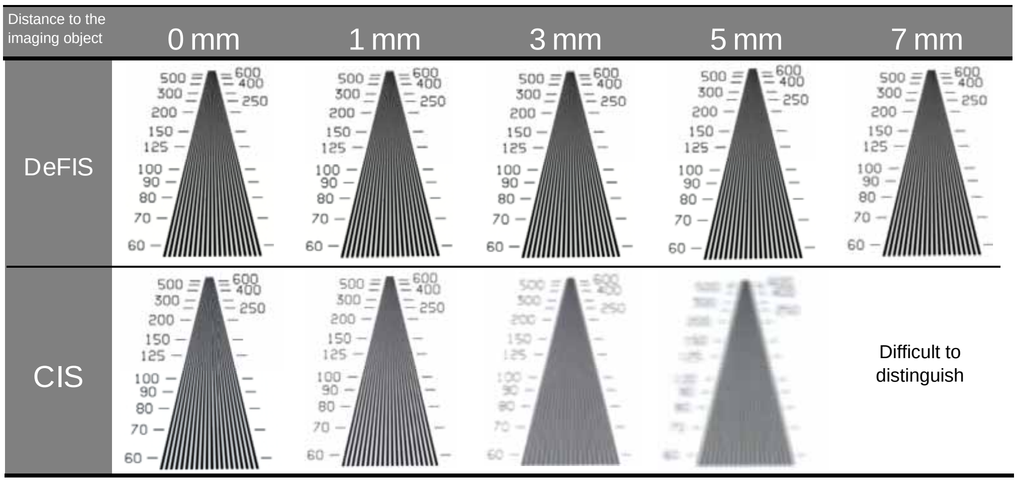

Fig. 3 Comparison of resolution

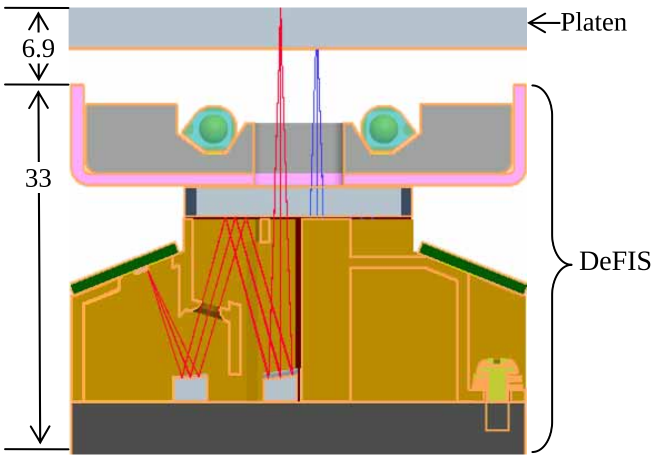

Fig. 4 Cross-sectional view of the DeFIS

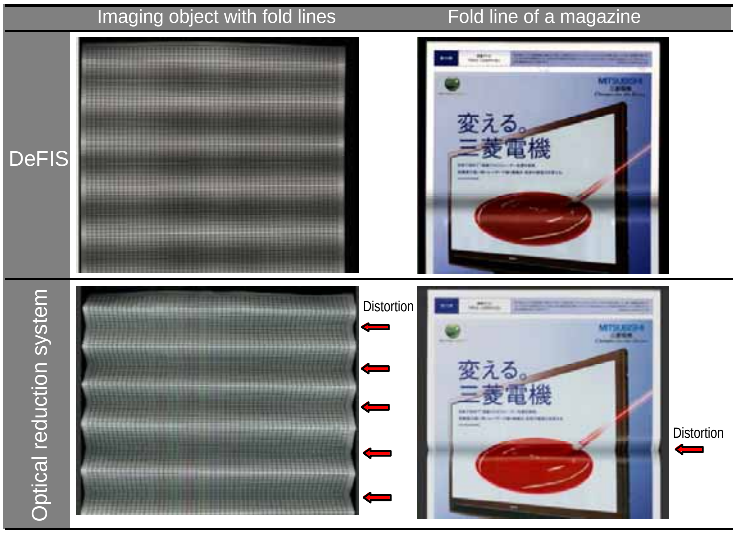

Fig. 5 Comparison of image distortions

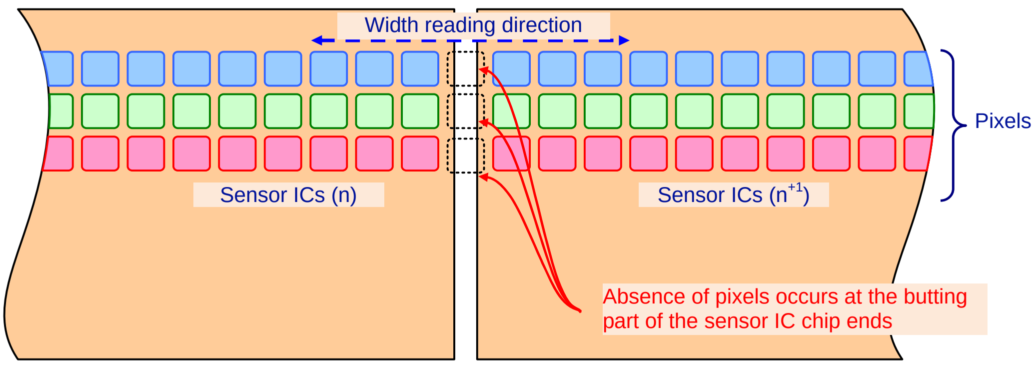

Fig. 6 How the absence of pixels occurs

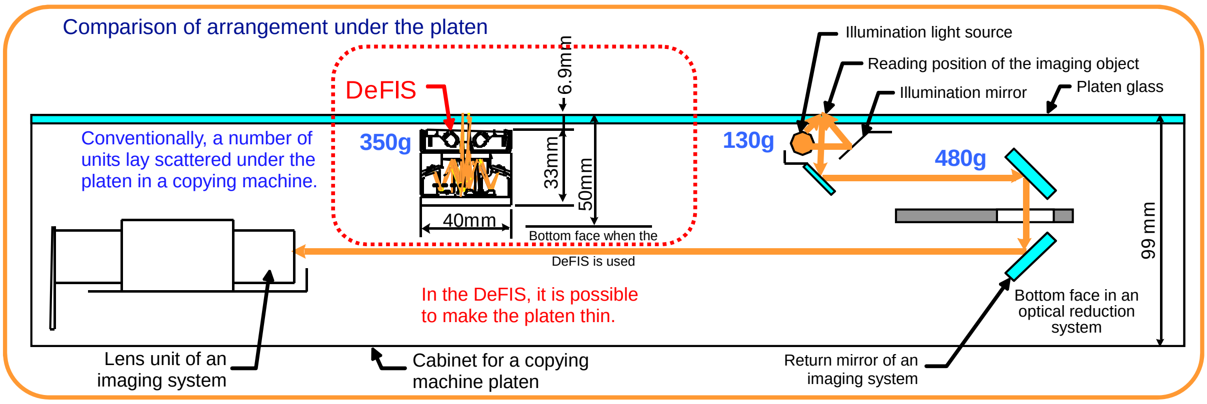

Fig. 7 Comparison of arrangement under the platen

A reduction in size comparable to CISs has been achieved while attaining the same performance as flatbed scanners of conventional copying machines, thereby enabling the entire system to be made smaller (Fig. 7).

2. Conclusion

This paper described the features of the deep field image sensor developed by Mitsubishi Electric and the element technologies. The device enables downsizing comparable to CISs with the same performance as flatbed scanner of a conventional copy machine. Thus, copying machines with these deep field image sensors can be made smaller with a simpler mechanism. We hope that this product boosts the copying machine market. We will continue to develop the seeds of new technologies and reading devices in other fields.

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