The Low Distortion All-Around View System Using Fisheye Lens For An Underwater Vehicle

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Abstract-**The visual information is one of very important information to operate underwater vehicles which are operated by human. So most unmanned vehicles and remotely operated vehicles (ROVs) are equipped with TV cameras. However the angle of view of the general TV camera for underwater becomes very narrow because of the optical refraction caused by the view port and sea water. In particular, human feel narrow about the horizontal angle of view. So we propose the charge coupled device (CCD) image sensor with a fisheye lens, which provides about 180 degrees horizontal angle of view, as the TV camera for underwater vehicles. And a prototype of the low distortion all-around view system using that for the underwater vehicle was made. As the result of experiment in the water tank, good images were appeared by the system.**

Figure 2. Operation consol for Kaiko.

I. INTRODUCTION

Recently, various types of underwater vehicles have contributed for the marine research field. They are classified into three general types; a manned vehicle, a remotely operated vehicle (ROV) and an autonomous underwater vehicle (AUV). Generally, the AUV provide an extensive seafloor survey using acoustic sensors because it has an ability to cruise continuously for a long time without cable connected to a support ship. The manned vehicle is operated by some pilots who are on board it, and they can directly observe the situation and the environment of the outside world from the pressure porthole. However its visibility is very poor because it is very small and very thick. Fig. 1 shows the pressure porthole of Sinkai2000 [1] as an example. Meanwhile the manned vehicle is also equipped with TV cameras. They can know the outside world from TV images and operate the vehicle body and manipulators watching the TV images. This is same as the observation and navigation of the ROV. In the ROV's case, some operators, who are board on the support ship, remotely control its body and manipulators watching TV images sent from it, and the outside world is known by the TV images. So most manned vehicles and ROVs are equipped with TV cameras. However the angle of view of the general TV camera for underwater becomes very narrow because of the optical refraction caused by the view port and sea water. Fig. 2 shows the TV monitor and the operator of Kaiko-7K [2]. In particular, we feel narrow about the horizontal angle of view. For that reason, previously, in order to know the outside world of the wide range, manned vehicles and ROVs must be equipped with a number of horizontally-arranged TV cameras. However this is not realistic for small vehicle, and also, this needs extra payloads and high-capacity image communication system. To make matters worse, this is an expensive

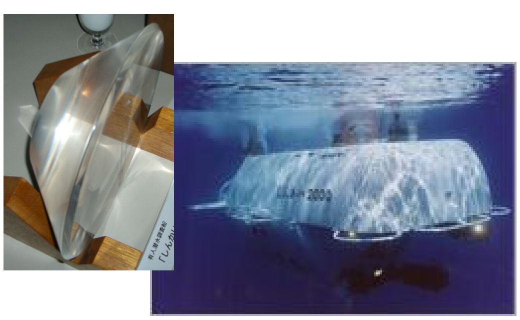

Figure 1. View port of Shinkai2000.

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Figure 3. Appearance of the prototype of the low distortion all-around view system

proposition. So we propose the charge coupled device (CCD) image sensor with a fisheye lens as the TV camera for underwater. It can provide about 180 degrees horizontal angle of view and any underwater vehicle can be equipped with it because its size is very compact. And the cost to mount it on an underwater vehicle is not expensive. What's more there is possibility that existing image communication system can be applied. However there is a big problem to realize such all-around view system. It is the distortion cased by the fisheye lens and other factors. In this paper, we describe about the prototype of the low distortion all-around view system using the CCD image sensor with the fisheye lens for the underwater vehicle. This system provides an image of 180 degrees horizontal angle of view to three displays separately. The distortion of the image is corrected and projected orthographically. In order to confirm the utility of it, some experiments were conducted and it is compared with the existing view system.

II. PROTOTYPE OF THE LOW DISTORTION ALL-AROUND VIEW SYSTEM

In nature, the low distortion all-around view system is composed of two CCD image sensors. And fisheye lenses are mounted on each one respectively. And the CCD iamge sensors with fisheye lenses are installed into each pressure halls. The pressure halls are equipped with glass view ports. Their shape is hemisphere and their sphericity is good possible. And they are fleshy in order to endure the water pressure of about a hundred Mega-Pascal from several dozens Mega-Pascal. Now, just the one set has been made because of the financial and timelike reasons. And the endurance of the pressure hall and the glass view port are 30 Mega-Pascal and 100 Mega-Pascal respectively because the view port is a backup supply of the 10,000 meters class ROV to cut back on costs. Its outer diameter and inner diameter are about 137 millimeters and 101 millimeters respectively. Its thickness is about 18 millimeters. So its size is large as compared with the diameter of the camera lens. The hardware construction of the prototype of the low distortion all-around view system is the CCD image sensor with the fisheye lens and the glass view port mounted on the pressure hall. Fig. 3 shows the appearance of the prototype system. Its whole weight without connectors and cables is about 3.5 kilograms in the air and 1.3 kilograms in the water. The pressure hall is made by the aluminum alloy surface treated by Tufram. The CCD image sensor used in the view system has the high resolution of five mega pixels over and its size is very compact. Its dimensions (length x width x height) are 58 millimeters x 44 millimeters x 29 millimeters. And its weight is only 104 grams. Its maximum frame rate is 15 flames per seconds. It has two digital interfaces of dual bilingual IEEE1394b for camera control, video data transmission and power. Its transfer rates are 800 Mega-bit per second. The image sensor is set on the chassis which is fixed completely on the pressure hall. Then the set position of it is adjusted accurately. Since the video data is directly transmitted to the computer for the image processing via an underwater connector and cable, its raw image taken by the CCD image sensor can be appeared on the computer screen. Naturally, the low distortion image of the wide angle of view can be also appeared on computer screens.

Figure 4. Raw image taken by the prototype of the low distortion all-around view system.

III. DISTORTION CORRECTION AND DISPLAY SYSTEM

The raw image provided by the prototype of the low distortion all-around view system is the circular image with a lot of distortion because the fisheye lens is mounted on the CCD image sensor. Naturally, if the image is projected squarely, it includes a lot of distortion. Fig. 4 shows the raw image. Not only the distortion is caused by just the characteristics of the fisheye lens but also other factors case the distortion. Because the CCD image sensor is installed into the pressure hall with the glass view port and the environment to use it is under the sea. In order to correct the distortion, the optical refraction cased by such factors must be compensated. So we carried out experiment using the prototype of the view system in the high water pressure tank. And the influence of them on the distortion of image was verified. As the result, part of it could be formulated. But that can not be described in this paper because we are now preparing the application of patent about that.

The prototype of the low distortion all-around view system provides an image of about 180 degrees horizontal angle of view. And its distortion is corrected and projected orthographically by the computer for the image processing. So we made the display system to appear the wide image at a time. Fig. 5 shows the image appeared on the display system. It is composed of three displays that the resolution of each one is defined as 1,024 x 768 pixels, and they are arranged horizontally in series. So the total resolution for three displays is 3,072 x 768 pixels. Each one appears the image of about 60 degrees horizontal angle of view, and each vertical angle of view is 43 degrees. The computer for the image processing receives the raw image form the prototype of the low distortion all-around view system, and it corrects the distortion of the image. After that, it appears divided images on each display. Therefore the display rate is slow down as compared with the original flame rate of the CCD image sensor.

Figure .5 Image appeared on the display system.

IV. METHODS OF APPLYING THE SYSTEM TO UNDERWATER VEHICLES

As described above, the prototype of the low distortion all-around view system has just a CCD image sensor. But, in nature, it has to be composed of two CCD image sensors. And there are several methods to apply it to an underwater vehicle. For example, if each one is set up in the front part and the rear part of the underwater vehicle, the all-around view of its traveling and passing direction can be provided by just two CCD image sensors as shown in Fig. 6(a). In this case, pilots of the manned vehicle and operators of the ROV can know the condition and situation of the outside world which is needed to control it. Meanwhile, if each one is set up in the upper part and the lower part of the underwater vehicle, the all-around view of its diving and passing direction can be provided by just two CCD image sensors as shown in Fig. 6(b). And in this case, the pilots and operators can observe the seafloor condition in a wide scope when the underwater vehicle approaches closer to the seafloor.

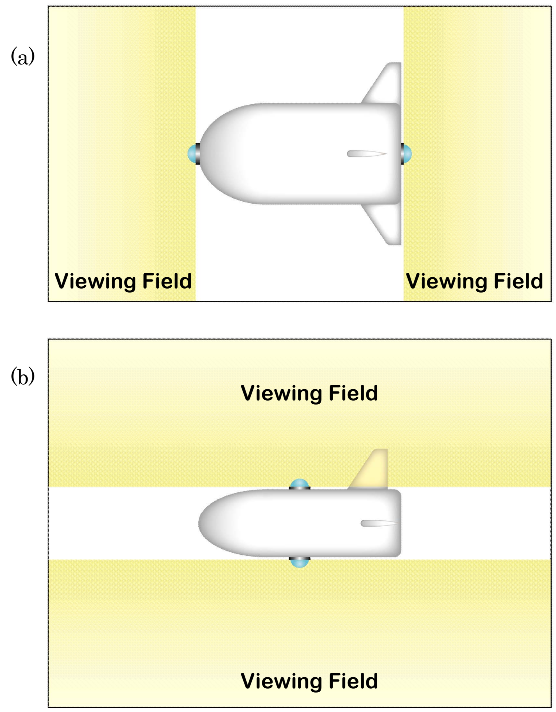

Figure .6 Arrangement of CCD image sensors for the low distortion all-around view system .

V. EXPERIMENTS AND RESULTS

In order to confirm the utility of the prototype of low distortion all-around view system, some experiments were carried out.

At first, the experiment to compare the angle of view of the prototype system with that of a CCD image sensor with a general lens was carried out. In this experiment, they took our laboratory room at a same position. TABLE I shows specifications of each CCD image sensor and lens. Fig. 7 shows images taken by each. As can be shown, Sine the prototype system provided about 180 degrees horizontal angle of view, the image appeared the wide scope environment. Then its vertical angle of view of the image was adjusted to

TABLE I
SPECIFICATIONS OF CCD IMAGE SENSOR AND LENS

Symbol	prototype of low distortion all-around view system	CCD image sensor with a general lens
Sensor Type	Kodak and Sony progressive scan interline transfer CCD's with Square pixels and global shutter	Kodak and Sony progressive scan interline transfer CCD's with Square pixels and global shutter
Resolution	2448 x 2048	1624 x 1224
Pixel Size	3.45um x 3.45um	4.4um x 4.4um
Data Output	24-bit digital data	24-bit digital data
Frame Rage	15 FPS	15 FPS
Shutter Speed	0.02ms to greater than 10s	0.02ms to greater than 10s
Lens Type	FE185C046HA-1	HF9HA-1B
Lens Focus	1.4mm	9mm
Lens Diaphragm	F1.4-16	F1.4-16
Horizontal Angle of View	185 deg	52.06 deg
Vertical Angle of View	185 deg	40.16 deg

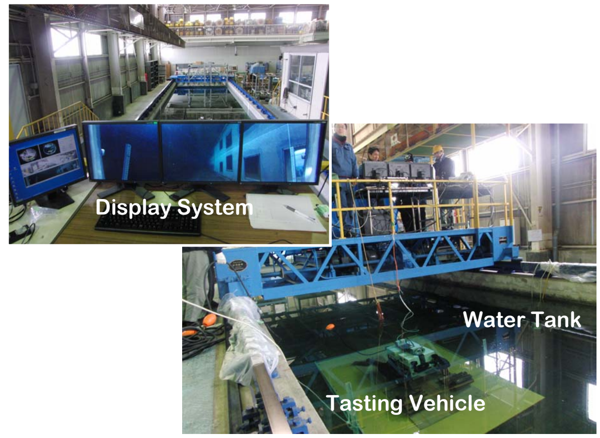

Figure .8 Experimental environment.

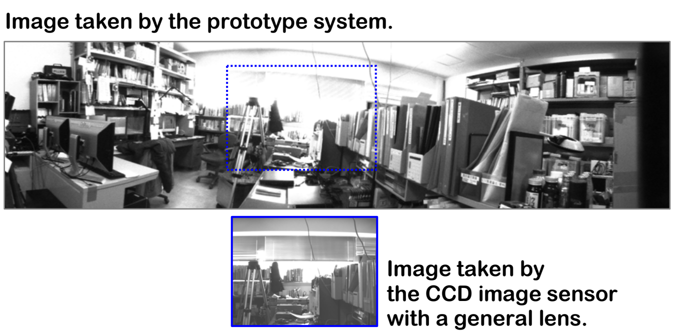

Figure .7 Images taken by the prototype system and a CCD image sensor..

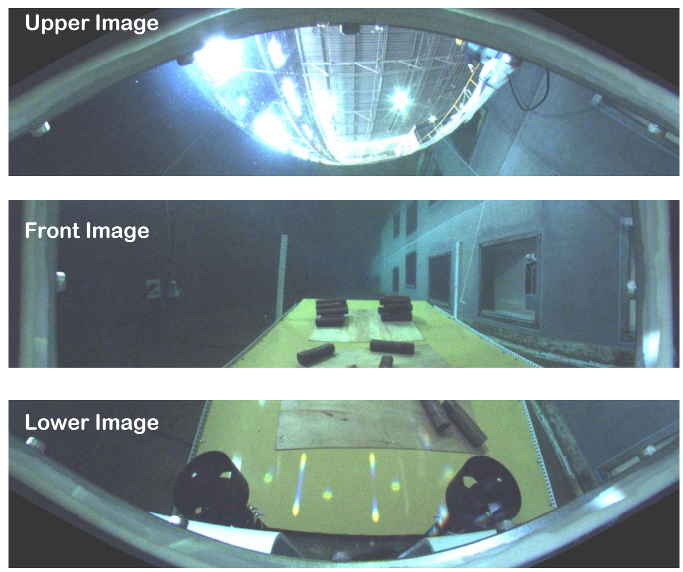

Figure .9 Images taken by the prototype system in the water tank.

about 46 degrees. Meanwhile, the image, which was taken by the CCD image sensor with the general lens, appeared only scope by about one-third because its horizontal angle of view is about 50 degrees. And its vertical angle of view of the lens is about 40 degrees.

At Next, in order to confirm the utility of the prototype system in the water, the experiment was carried out in a water tank. Fig. 8 shows the experimental environment. The prototype was mounted on a testing vehicle and it was in the water tank. There was a slope road with obstacles for a test run of the vehicle in the water tank. The computer for the image processing and the display system were set on the water tank. The image taken by the prototype system could appear the wide scope of the inside of the water tank as shown in Fig. 9. And the prototype system can take upper images and lower images at any direction because it can adjust its view vector in its vertical angle of view.

VI. CONCLUSIONS

In this paper, the prototype of the low distortion all-around view system using the CCD image sensor with the fisheye lens for the underwater vehicle is described. It provides an image of about 180 degrees horizontal angle of view to the display system. And the distortion of the image is corrected and projected orthographically by the computer for image processing. As results of experiments, wide scope views were appeared in the air and water. We are now study the algorithm to reduce further the distortion of image. And in near future, we will develop the real type of this system which is composed of two CCD sensors, and apply it to a real underwater vehicle.

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