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Development of the ship-mounted underwater acoustic surveillance system

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ABSTRACT

Possibility of terrorism from the sea front and maritime crimes using the water space tends to increase and development of underwater monitoring and visualizing technology would be desired. We developed the ship-mounted underwater acoustic surveillance system which can watch widely in the water space with mobility by mounting the sonar on ship. This is an underwater visualization sonar system with high resolution that efficiently detects and distinguishes the targets in real image and in real time. It is expected that this system is useful not only for finding of doubtful person or doubtful objects in the water in which we cannot observe until now but also for search of the sunken ship, underwater security and investigations in the harbor area and so on. In this paper, mechanism and imaging principle of the underwater acoustic surveillance system are briefly described and results of the operational test in the actual sea area carried by mounting the sonar on the test ship are introduced.

INTRODUCTION

Since the 9.11 simultaneous terror attacks in U.S.A., the development of protection or security system for terrorism and sabotage, which are very complicated and ingenious, has been rapidly advanced in U.S.A. and European countries. On the other hand, possibility of underwater terror attacks and maritime crimes such as smuggling of narcotic and weapons, poaching of the seafood, illegal disposals of toxic substance tends to increase in the recent years [1]. In Japan, especially, as all infrastructure facilities such as power plant and petroleum and industrial facilities concentrate almost in the coast, development of underwater protection or security system seems to be a matter of great urgency. However, since usual optical video system is not so useful in the water, underwater security has not been argued so much until now.

In these situations, 3-years promotion program, begun in 2005, entitled "Development of the underwater security sonar system" has been carried out with the support of the Special Coordination Funds for the Promotion of Science and Technology of the Ministry of Education, Culture, Sports, Science and Technology in JAPAN [2-4]. This program intends to realize the integrated monitoring of water space in the coastal zone by watching, tracking and distinguishing the dangerous target with high resolution by using the underwater ultrasonic wave. In the field of underwater security, this was done for the first time in Japan. As a part of this program, we developed the ship-mounted underwater acoustic surveillance system that can watch widely in the water space with mobility. It makes possible to realize the quick transfer to the monitoring zone required and the efficient watch and search by mounting the sonar on ship such as the patrol vessel. Moreover, it is an underwater visualization sonar system with high resolution that efficiently detects and distinguishes the targets in real time by switching over the optimum frequency according to the distance from the sensor to targets or the size of target. Then, it is expected that this system is useful not only for finding of doubtful person or doubtful object in the water in which we cannot observe until now but also for search of the sunken ship, underwater security and investigations in the harbor area and so on.

In this paper, mechanism and imaging principle of the underwater acoustic surveillance system are briefly described and results of the operational test in the actual sea area carried by mounting the sonar on the test ship are introduced.

MECHANISM AND IMAGING PRINCIPLE OF UNDERWATER ACOUSTIC SURVEILLANCE SYSTEM

Ship-mounted underwater acoustic surveillance system is constituted from the acoustic radar and the acoustic video camera. Here, we call the "acoustic radar" at present stage as it is similar to pulse-echo radar by radio wave. Figure 1 shows the photograph of each acoustic sensor and Table I gives their specifications. Both acoustic sensors radiate the ultrasonic wave in the water and are obtained azimuth and distance up to the submerged objects by returning echoes reflected from the objects. The former acoustic radar searches at large angle of visibility with long way, and the latter acoustic video camera detects and visualizes the objects in detail with short range comparatively.

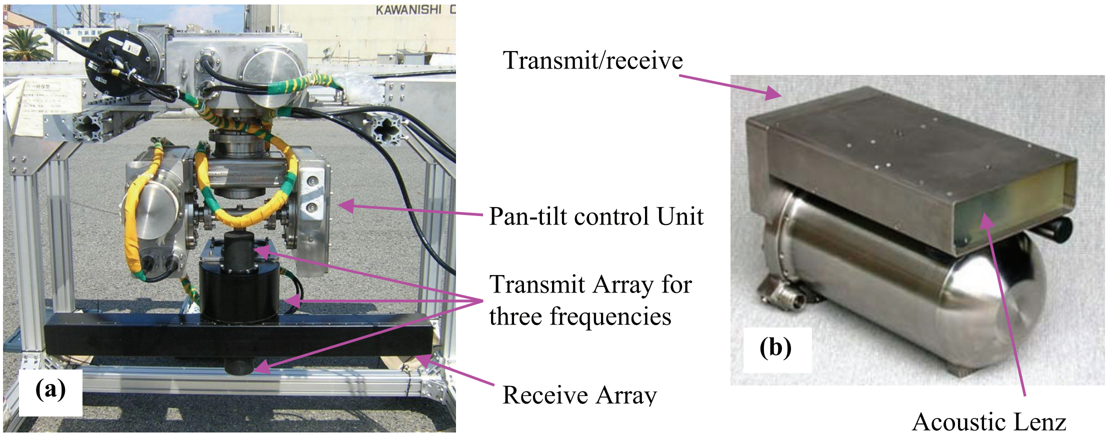

Figure 1 Underwater acoustic surveillance system constituted from (a) Acoustic radar and (b) Acoustic video camera.

Table I Specifications of the underwater acoustic surveillance system.

	Acoustic Radar (SeaBat 7123)			Acoustic Video Camera (Standard DIDSON)	
Frequency band	100 kHz band	200 kHz band	400 kHz band	MHz (LF)	MHz (HF)
Max Range	closed			closed	
Horizontal Coverage	120°	90°	45°	29°	
Number of Beams	256			48	96
Pan Tilt Control	H : ±90°, V : +5 ° to −90 °			Manual	

The principle of the acoustic radar is the same as the multi-beam echo sounder which is well-known the submarine prospecting equipment using acoustic wave [5, 6]. In the case of the echo sounder, acoustic wave is almost perpendicularly transmitted for sea bed and water depth is obtained at the good accuracy from the time-of-arrival of reflective echo. In the case of acoustic radar, sound beam is radiated with a degree of shallow illuminating angle from 20° to 30° for water surface and underwater image is obtained by the reflective echo from the sea bed or objects existing forward. The Acoustic radar is composed of the 3 wave transmissions having the 3 frequencies (100 kHz, 200 kHz, 400 kHz band) respectively and the echo sounder receiver (the line array) that were made from many vibrators by arranging linearly. The acoustic beam of proper frequency is transmitted from the either wave transmission under the sea surface and various echoes return after reflecting from the sea bed or objects in the water. The receiving wave slit with narrow width in longitudinal direction is formed by the echo sounder receiver of the line array and the reflective echoes of 256 scanning line states can be obtained by sampling through this narrow slit (two-dimensional scanning by the Phased Array Method). Finally, an image of sectorial 1 sheet is generated by sticking the receiving wave beam (scanning line) with narrow width.

On the other hand, the acoustic video camera, which is called DIDSON (Dual-frequency IDentification SONar) as 2 kinds of ultrasonic pulse of the MHz region are used, it is an underwater visualization sonar which can observe forward at short range with high-resolution and in real time [7]. The imaging principle is similar to the acoustic radar as below. Firstly, ultrasonic acoustic pulse beams with the narrow width are irradiated from each wave element through the acoustic lenses of three-layer structure. Secondly, reflective echoes from the sea bed or underwater objects are converged by the same acoustic lenses and an image of sectorial 1 sheet is generated by sticking the 48/96 scanning lines. In case of the acoustic video camera, angle of visibility is narrow of 29° because the beam forming is done using the acoustic lenses like above. However, installation to the small craft and the correspondence for emergency become possible, since the system is very simple and the handling is very easy.

Either case of the acoustic radar and the acoustic video camera, the distance between the sonar and the object corresponds to the time-of-arrival of the reflective echo from the object and the tone of sonar image corresponds to the intensity of acoustic wave. Therefore, it is described that the object near the sonar appears at short range and the one far from the sonar appears in the distance. And the strong reflective echo from the object is brightly displayed in sonar image and the weak reflective echo or the shadow of the object, which was not exposed to the acoustic wave (shadow zone), is dark displayed. From this shade or shadow, it is possible to get the image close to the real image of the object on the sea bed. This is the just characteristic point of the present underwater acoustic surveillance system. And, it is also excellent that the frequency of the acoustic sensor can switch over according to the size of target and the distance to target as this system has 5 kinds of ultrasonic pulse from the 100 kHz band to the MHz band. Therefore, more efficient underwater watching and searching become possible. In addition, since the forward aspect is obtained as a real-time image even in the quiescent state, it is expected that this system is useful for the last confirmation which replaces the diving operation in survey of dangerous object such as explosive substance, monitoring of the objects which float and moving in the water, search in city harbor area in which the visibility is fairly bad, ships congestion sea area or around the wharf, etc..

OPERATIONAL TESTS IN THE ACTUAL SEA AREA

In the followings, we introduce the operational tests in Kobe and Yokohama harbours by mounting the underwater acoustic surveillance system on the test ship. The training ship of "Itsumori" (18 m, 16 tons) in Coast Guard Academy was used in Kobe harbor, and the survey vessel of "Hamashio" (17 m, 27 tons) in getting the cooperation of 3rd Regional Maritime Safety Headquarters was used in Yokohama harbor.

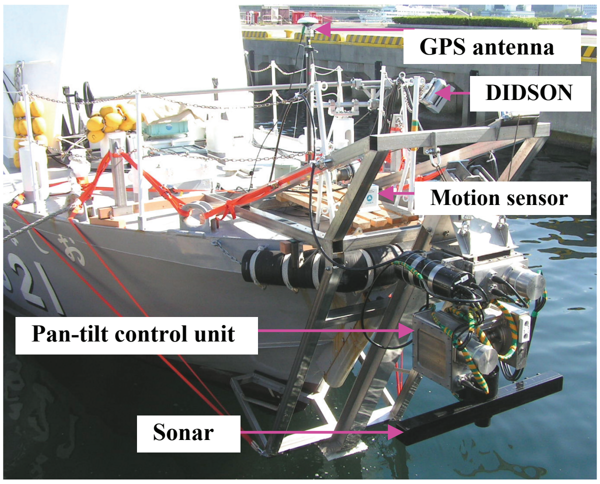

Figure 2 Underwater acoustic surveillance system mounted on the stem of the survey vessel of "Hamashio".

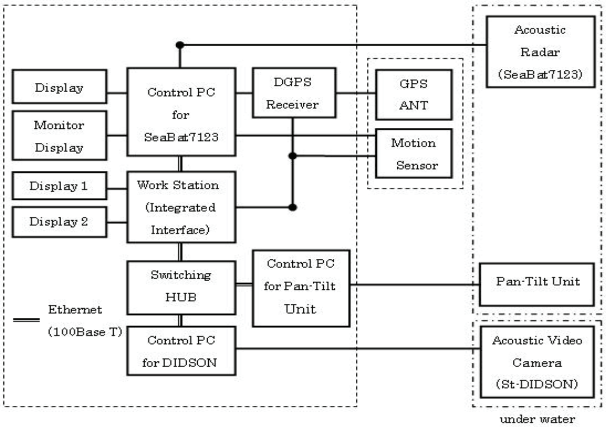

Figure 3 Configuration of the ship-mounted underwater acoustic surveillance system.

Figure 2 shows the underwater acoustic surveillance system installed in the stem of the survey vessel of "Hamashio". Each acoustic sensor was fixed in the test ship by the exclusive mounting jig which gave the pan tilt function. Therefore, it is possible to turn the sonar to target from shipboard in the remote manipulation for the change of the attitude of the ship by tidal current and wind. It is also possible to watch the wharf and its circumferences, while sailing at the speed under 5 knots. Each acoustic sensor was lowered in the water about 1.5m depth along with slewing gear and underwater images were photographed. If the sensor is raised on the water surface, the sailing in the usual speed of ship is possible. Then quick transfer to the monitoring zone and efficient monitoring and searching can be carried out. In addition, GPS antenna and its receiver were installed in the vicinity of acoustic sensor to obtain precise position information and the inertial navigation system (the optical fiber gyrocompass) was installed to obtain azimuth and inclination information. These data were also acquired together with the underwater view-data. The configuration of the ship-mounted underwater acoustic surveillance system is shown in Figure 3.

RESULTS

Underwater search in the coastal zone

In the case of underwater search in the coastal zone by the underwater acoustic surveillance system, it is necessary to select the optimum frequency according to the survey sea area or the targets. It was found that the 200 kHz band of the acoustic radar, which has comparatively wide search width and high resolution, is the optimum frequency in the wide search of the sea area for several 10 m depth. As an example, the image which photographed the various artificial reefs in Suma open sea near the Kobe harbor is shown in Figure 4. This figure is obtained by the acoustic radar of 200 kHz band with range of 125 m and width of about 180 m. Arrangements and shapes of various artificial reefs can be distinguished on the smooth sea bed. And it is also recognized that some objects are buried in the sea bed and many dents

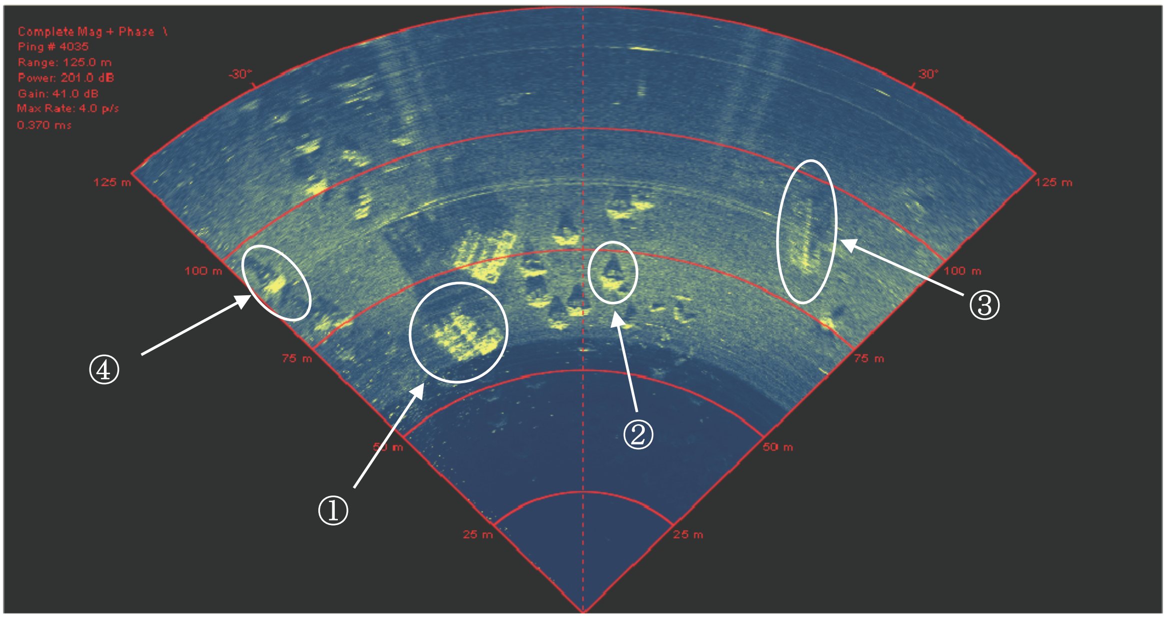

Figure 4 Monitoring display of the acoustic radar (200 kHz band, Maximum range is 125 m). Various artificial reefs are observed at the sea bed in Suma open sea area near the Kobe harbor. ① Large-size box type artificial reef. ② Conic type artificial reef. ③ Half-buried object. ④ The dark part in the front of the object is the dent on the sea bed and the dark part behind the object is shadow.

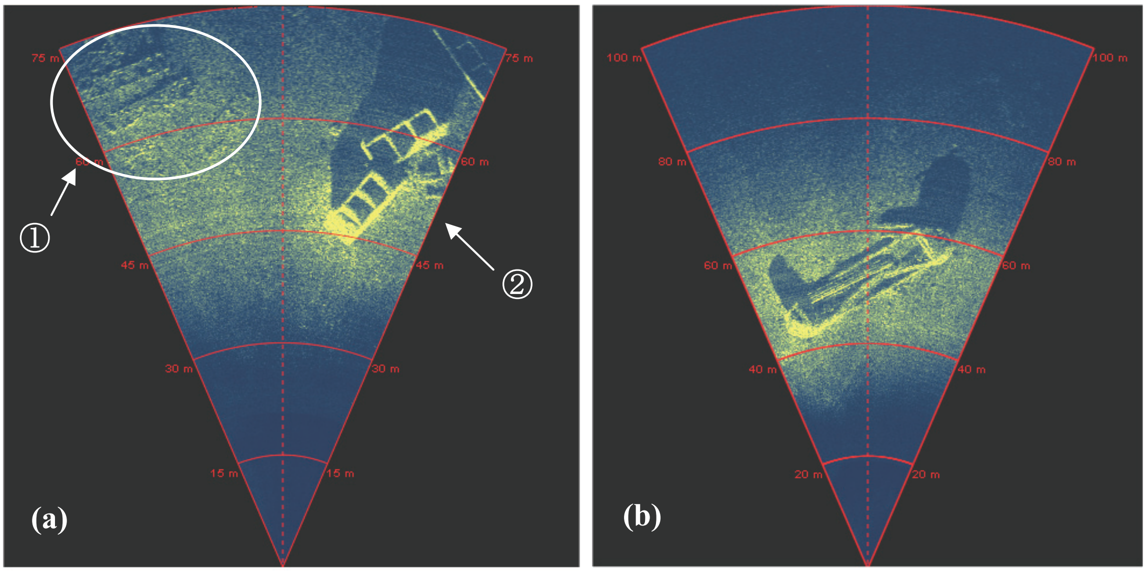

Figure 5 Detailed image of the artificial reefs in Suma open sea area. (a) 400 kHz band, Maximum range is 75 m. ① Objects buried in the sea bed. ② Large-size box type artificial reefs. (b) 400 kHz band, Maximum range is 100m, Barge type sunken ship that was partly buried under the sea bed. Before and behind division is high and ship side is bent.

appear on the sea bed. Furthermore, the height of the object can be read roughly from the length of the shadow in the sea bed, when the acoustic wave goes straight and the sea bed is flat. Figure 5 shows the images photographed in detail by 400 kHz band in respect of box structure objects and barge type sunken ship. In the Figure 5(a), in addition to large-size box type artificial reef, it can recognized that existence of the objects like street cars buried almost in the sea bed (denoted by the circle in the figure) which had been installed as a artificial reef about 30 years ago. From the Figure 5(b), it can be read that the barge type sunken ship have a structure of the length about 34 m and the width 7 m, the height of the before and behind division is about 3 m, and the ship side is bent inside, etc. If we photograph while orbiting around the object, we can know in detail the whole aspect of the objects, for example, the attitude or the damage of the wrecked ship on the sea bed and so on. These results show that the acoustic radar of 200 kHz band was effective for search in the wide sea area such as the wrecked pleasure boat and the large construction wastes on the sea bed. And if the 400 kHz band is used jointly, we can confirm the detailed situation of the objects on the sea bed as below; whenever the objects were partly buried or not, the ship hull was damaged or not, the ship's load was scattered or not and so on.

Observation of underwater structure and search of doubtful objects in the harbor

As an example of observation of underwater structure, an image photographed near the primary pier western edge in Kobe is shown in Figure 6. In the Figure 6(a), obtained by in 200 kHz band, whole structure of the pier western edge can be seen that the stone pavement continues from sea bed toward the pier. Figure 6(b) is the detail image obtained by 400 kHz band paying attention to the base of the pier edge denoted by the circle in the figure. The wave removal block and individual shape of the stone pavement can be recognized in more detail. If the distance from the sensor to target is within about 30 m, it seems that objects of several decade cm on the caisson or dead body twined around the wave removal block can be distinguished from the shade and shadow in the sonar image. Like the above, the ship-mounted underwater acoustic surveillance system is effective for observation and monitoring of underwater structure, etc.

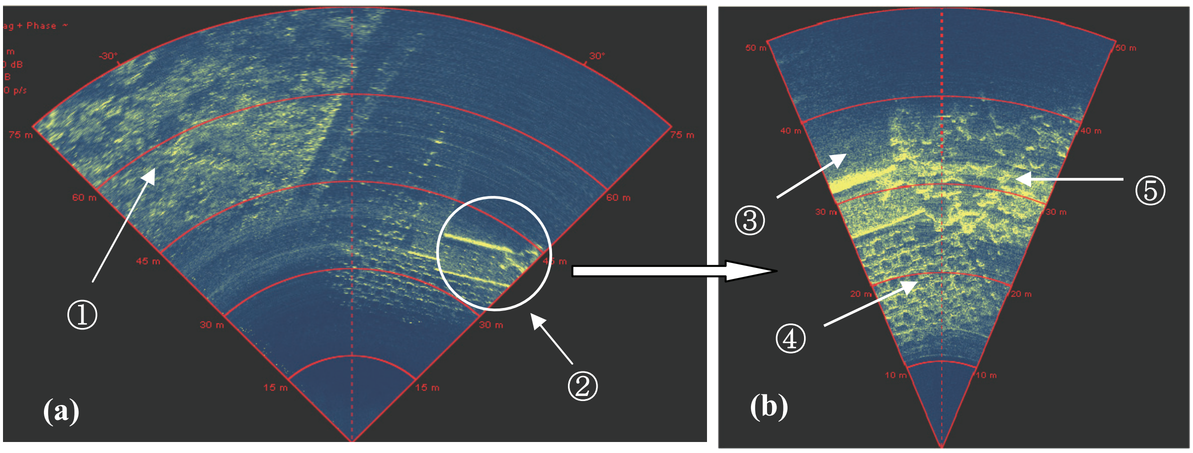

Figure 6 Image of the primary pier western edge in Kobe photographed by the acoustic radar. (a) 200 kHz band, Maximum range is 75 m. ① Sea bed. ② Base of the pier edge. (b) 400 kHz band, Maximum range is 50 m. ③ Concrete caisson. ④ Stone pavement. ⑤ Wave removal block.

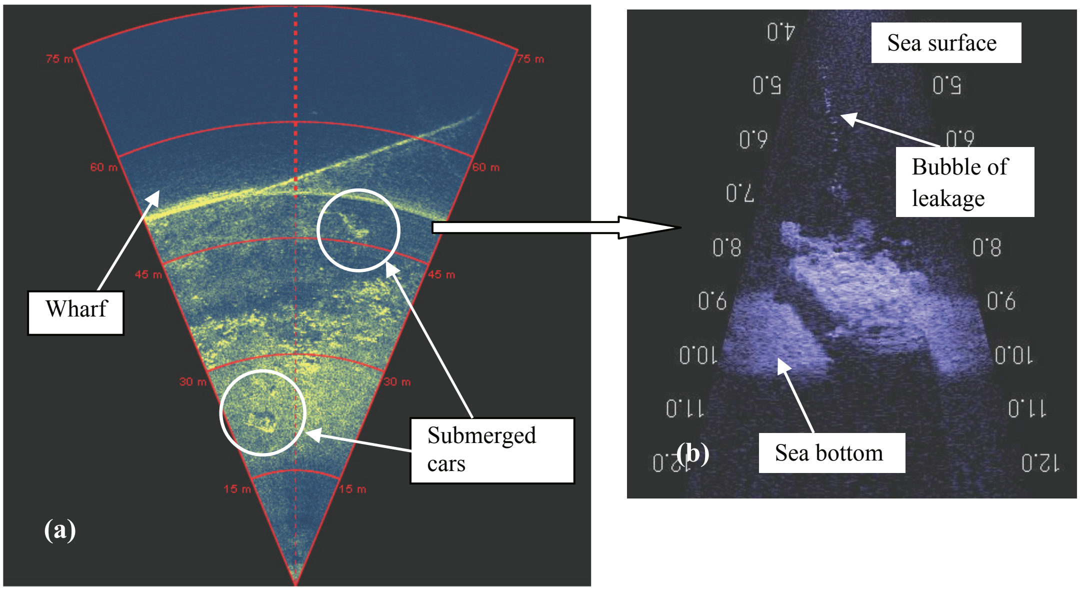

Figure 7 Submerged rolling cars near the second jetty in Kobe new wharf. (a) Ship-mounted acoustic radar image (400 kHz band, Max. range is 75 m). (b) Detailed image by the acoustic video camera (MHz band (HF), Maximum range is 12 m). It can be finally judged the submerged rolling car from this image.

As a result of underwater search around the Kobe new harbor, 2 submerged rolling cars were discovered near the second jetty and 3 cars were discovered near the east wharf. Figure 7 shows the image of the submerged rolling cars near the second jetty photographed by the acoustic radar and the acoustic video camera. Figure 7(a) is the image photographed by the acoustic radar of 400 kHz band. The 2 objects like cars are found at the places of about 5 m and about 28 m from the wharf, which are surrounding by the circles in the figure, respectively. The bed sill of the wharf gently rises toward the wharf and there is a large number of pebbles, etc. Quadrangular 2 objects can be clearly distinguished from other objects. Among the two objects which seem to be submerged cars in Figure 7(a), the detailed image was obtained by using the acoustic video camera getting the sight on the one near the wharf (8 m water depth). Result is shown in Figure 7(b). From the Figure 7(b), 4 tires and shafts can be distinguished and it can be finally judged the submerged rolling car. And, it can be also read that the leakage thing like the bubble rises from the central region of car body to the sea surface. Except for the submerged rolling cars, the traces on the sea bed which dragged by the anchor and old wharves before the Earthquake Disaster in 1995 are observed in Kobe harbor. These results show that the acoustic radar of 400 kHz band can easily detect and distinguish the targets for the purpose of the search in doubtful object at the harbor such as a submerged rolling car. And it is effective to use the acoustic video camera in the pinpoint on the basis of the position information by the acoustic radar for obtaining the more detailed image.

Superimposed display of radar image into the Electronic chart and mosaic image

In the operational tests of ship-mounted underwater acoustic surveillance system, information of the accurate position and the azimuth-inclination of acoustic sensors are always taken in by GPS receiver and inertial navigation system, respectively, on acquiring the underwater sound image. So, we would be able to display the longitude and latitude calculated from the acoustic wave route when the cursor is put on the monitor screen of the acoustic radar. Then, we can grasp the position information of the doubtful object discovered by this surveillance system immediately. Furthermore, the development of superimposing display of the acoustic radar image on the marine chart taken in advance was carried out. Figure 8(a) shows the monitor screen which superimposed radar image into the marine chart (head-up display) when we have photographed the artificial reefs in the fishing pier of Honmoku wharf and its offshore in Yokohama harbor by the acoustic radar of 200 kHz band. The sonar operator and the ship operator can search the object in the water and handle the ship while photographing position and photographing direction are confirming on the marine chart by this application function. Therefore, it is very useful in the operation of capture of the target. In addition to this, an example of the mosaic image made from the radar image obtained in this Honmoku area is shown in Figure 8(b) [8]. Though it consists any time in dealing, it is considered to be greatly useful in the practical aspect to grasp the whole image of searching sea area.

CONCLUSION

Ship-mounted type underwater acoustic surveillance system which can freely move on the sea surface and watch in the water space with mobility was developed. This is an underwater visualization sonar system with high resolution that efficiently detects and distinguishes the targets in real image and in real time. Therefore, it seems to become large support not only to the field of underwater security such as monitoring in the water in which we cannot observe until now but also to the maritime safety business, for example, crime control using undersea space such as smuggling, poaching and the unlawful throw, marine disasters search of sunken ships, search for doubtful objects or missing person in the coastal zone, etc. Until now, underwater search such as the doubtful objects or missing person has been mainly due to the visual observation by diving in the water actually. These are very hard and difficult operations in the case of impure sea area, ship congestion sea area, rocky stretch sea area, especially, at night. The present underwater acoustic surveillance system will become effective as a means of the last confirmation which replaces the diving operation in city harbor area in which visibility is very bad and ship congestion sea area, complicated region like between jetties around the wharf, even at night. Beyond that, the utilization in wide fields such as ocean engineering field and marine product engineering field can also be expected.

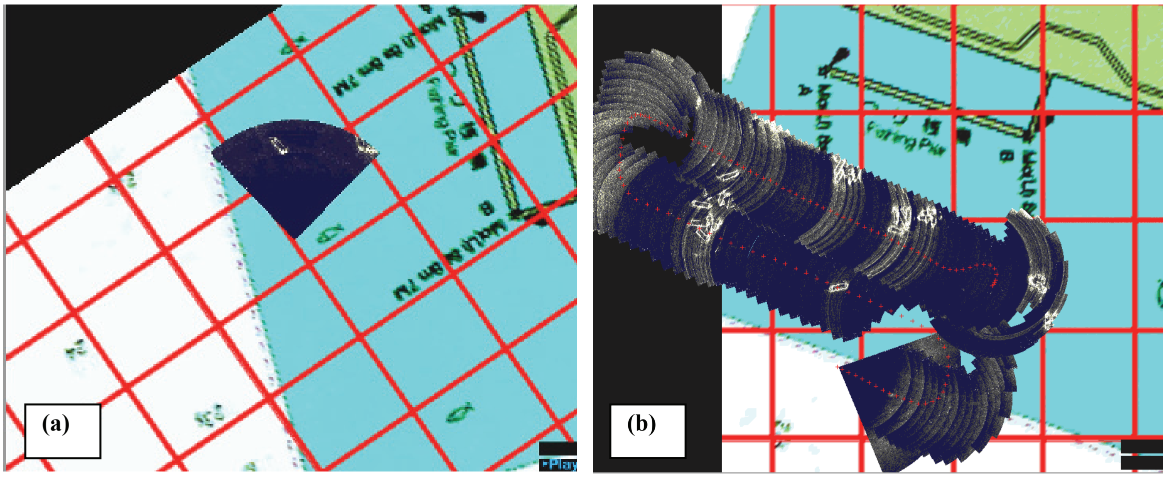

Figure 8 Monitoring display of the artificial reefs in the fishing pier of Honmoku wharf and its offshore in Yokohama harbor photographed by the acoustic radar of 200 kHz band. (a) Monitor screen which superimposed radar image and marine chart (head-up display). (b) Mosaic image made from the acoustic radar image.

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