Application of deep learning to underwater invasion warning system

M. Ogawa, H. Tanaka, J. Muramatsu, M. Nakano, K. Yoshida and T. Asakura
NEC Corporation, Japan

***Abstract*—In this paper, we discuss our trying to improve detection performance of a diver detection sonar using deep learning in very shallow water area. We had developed and evaluated our underwater invasion warning system to detect intruders, diver and diver with swimmer delivery Vehicle (SDV), which try to intrude a harbor for several years. We find out that there are some demand for the underwater monitoring, especially in very shallow water area, less than ten meters depth. We have already known that such very shallow water makes difficult situation for sonar operation because reverberation is high and false alarms happen frequency than usual. We have already developed better way by analyzing detection parameters such as a signal level and a signal length by a statistical analytic method and solving the problem which uses an automatic optimization method of detection parameters. But in general, it is known that there is a trade-off relation between the reducing false alarms and good detection performance. There may be case that it is difficult to combine good reducing false alarms and good detection performance by a statistical analytic method. Therefore, we have worked on development of the method to solve the problem. In this work, we discuss the detection method using deep learning as one of our trying. Like general surveillance camera, a background image will be extracted. And we will detect the moving object by subtract difference between the background image and the current image. In this paper, we developed a new algorithm to detect moving object by the same way, which employs the differences between i) the observed current plan position indication image in short PPI image and ii) the predicted PPI image generated by deep learning as a background image. The training for the predicted PPI image was executed including the reverberation in the sea. Our proposed algorithm becomes** one of **the new detection method which does not use the conventional method using comparison with threshold value to decrease the false detection rate.**

***Keywords*—deep learning, diver detection sonar.**

I. INTRODUCTION

Recently, important infrastructures such as power plants, oil storage stations, airports and harbors in the coastal areas are faced a lot of dangers like illegal invasion, subversive activity by terrorists and criminals organization as well. On the land, we have already high security level by intruder detection system using cameras and radars, an access control system using biometrics or IC card and security check using terahertz wave etc. However, we usually don't consider intruders as underwater threat, on which big security hole exists. Since light and radio wave can't travel long range in the underwater, sonar is used.

We have already launched and been developing the underwater invasion warning system to detect and track underwater intruders, such as divers and diver with SDVs trying to intrude harbors and ports. We find out that there are some demand for the underwater monitoring, especially in very shallow water area, less than ten meters depth. We have already known that such very shallow water makes difficult situation for sonar operation because reverberation is high and false alarms happen frequency than usual. We have already developed better way by analyzing detection parameters such as a signal level and a signal length by a statistical analytic method[4] and solving the problem which uses an automatic optimization method of detection parameters. But in general, it is hard to keep the tracking targets continuously even if the false alarms could be reduced by using the optimum threshold level of detection parameters. These phenomenon are particularly seen in the very shallow water. Therefore, we have worked on development of the method to solve the problem. In this work, we discuss the detection method using deep learning as one of our trying.

II. UNDERWATER INVASION WARNING SYSTEM

We had developed and evaluated our underwater invasion warning system to detect intruders, diver and diver with SDV, which try to intrude a harbor for several years [1-4]. We already released the second production model of an active acoustic sensor is shown in Fig.1. The transmitter transmits a sound wave and the receiver receives the echoes to obtain the distance and direction of the target. The performance summary of an active acoustic sensor is shown in Table 1. Such a sensor may be installed on the seabed or on a bridge pier and the detection range is a radius of about 1,000 meters as a typical value in 360 degree range. General-purpose servers are used on the land side and the dedicated software is installed for sonar signal processing and display. An active acoustic sensor and servers of the land side are connected by underwater cable and acoustic data is gotten by the cable with 1000Base-T interface in real time.

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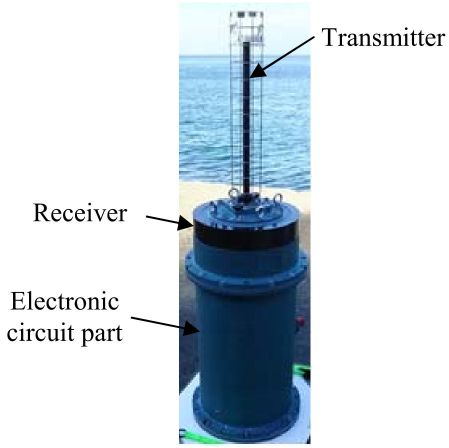

Fig.1 An active acoustic sensor

Table-1 The performance summary of an active acoustic sensor

No	Item	Performance
1	Transmission Frequency	75~95 [kHz]
2	Horizontal Coverage	360 [deg]
3	Interface	LAN(1000Base-T)
4	Maximum Operating Depth	50 m (Deeper options available on request)
5	Installation Location	Seabed or bridge pier (Under the water)

Next, the sonar signal processing flow diagram is shown in Fig.2. We applied some technologies such as signal processing, computer aided detection (CAD) process and computer aided tracking (CAT) using the multiple-hypothesis tracking (MHT) algorithm to our production and we have evaluated functions which are false alarms reduction, target detection and tracking. After processing result, detected targets are displayed as a symbol and alarmed to the sonar operator if the target score is estimated danger level.

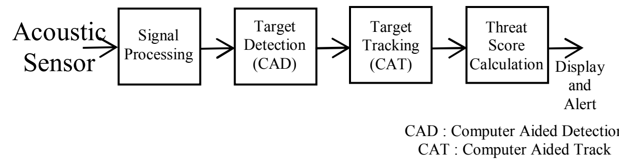

Fig.2 Sonar signal processing flow diagram

We are sonar manufacturer and we have long been developed from acoustic sensors to display and decision making system. We have the false alarms reduction technique against reverberation from sea-surface, seabed and ambient noise. Furthermore, we have the detection technique of echo which is buried in ambient noise deeply. We spent many years in the past for developing and improving the technique for long time as a sonar provider.

III. Evaluation in very shallow water

We were thinking that our sonar performance have already reached enough level. However, we find out that there are some demand for the underwater monitoring, especially in very shallow water area, less than ten meters depth. When we tried to evaluate our sonar in the very shallow water, we learned that there may be case which false alarms happen frequency. After that, we have developed better way by analyzing detection parameters such as a signal level and a signal length by a statistical analytic method to set optimum threshold level to decrease the false alarms rate [4].

In this paper, we don't use the data of the very shallow water, less than ten meters depth because of confidential data. We use the shallow bay area data at from ten to thirty meters depth instead of it. If we can show the results of the very shallow water, false alarms will increase more than the shallow bay area data.

Fig.3 shows an example of the result of a sea trial at shallow bay using conventional detection parameters, from ten to thirty meters depth, in November 2016. The target objects are two divers who are approaching to the sonar position. Two divers dive from a small boat at about 400 meters distance. The diver No.1 in the figure swam toward west from the diving point. Another diver No.2 turned to the sonar position after swimming toward south for a while. The thin lines of orange and yellow in the figure show diver's track which were gotten by GPS which diver had. But we don't express GPS position error and sonar detection position error in the figure. I just overlaid sonar detection result on the GPS track line. This figure shows that our sonar could detect the diver No.1 continually, but there were many false alarms.

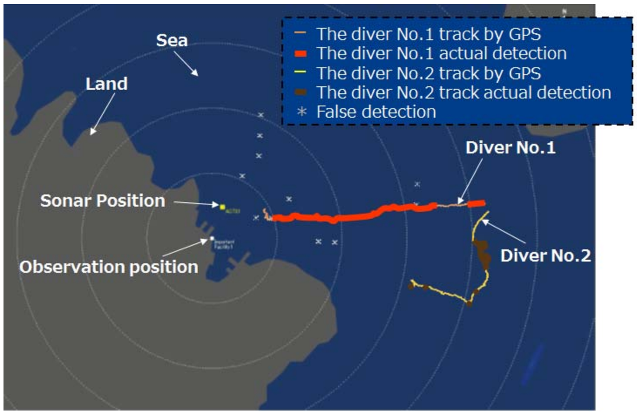

Fig.3 The result of a sea trial (conventional detection parameters)

Fig.4 shows another result after parameter tuning. We succeeded in reducing the number of false alarms as we expected. However, the tracking continuation became worse than the first parameters condition. We have to improve the detection performance and the continuance of target tracking if threshold level is optimized.

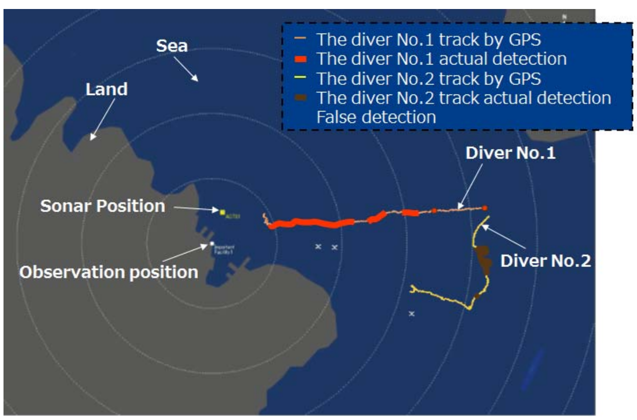

Fig.4 The result of a sea trial (after parameter tuning)

In general, it is known that there is a trade-off relation between the reducing false alarms and good detection performance. Fig.5 shows the diagram of detection determination when signal level of echo is bigger than noise and reverberation level. A part bigger than the threshold level is detected as a target. In this case, you can easily detect only echo without false alarms because echo level is bigger than noise and reverberation parts level.

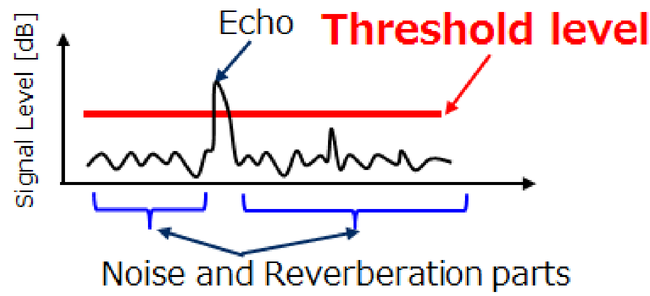

Fig.5 The diagram of detection determination when signal level of echo is bigger than noise and reverberation level

Next, Fig.6 shows the diagram of detection determination when signal level of echo is as big as noise and reverberation level. When echo level is low, you can't easily find echo because echo will be buried in noise and reverberation and you can't adjust the optimum threshold level which can detect only echo without false alarms because the optimum threshold level range will be very narrow. Therefore, it's difficult to keep good detection performance without false alarms.

We have worked on development of the method to solve this problem because conventional threshold level determination method can't expect enough detection performance in the very shallow water.

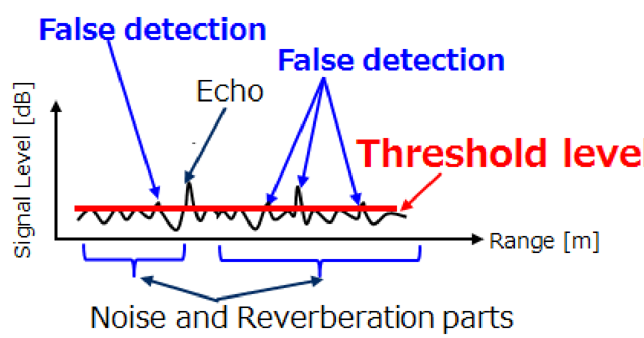

Fig.6 The diagram of detection determination when signal level of echo is as big as noise and reverberation level

IV. Application of Deep Learning

First of our trying, we couldn't distinguish between echo and reverberation determined as false alarms although we compared with features of signal level distribution of them. The transmission sound wave is bounced off sea-surface and seabed and makes reverberation. Therefore, the reverberation has the same characteristics as echo. However, Fig.7 shows that the echo moves slowly and we can find the moving echo

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even if the echo which is buried in ambient reverberation deeply. We tried to realize the moving echo by using something method in such ambient reverberation deeply. Fig.7 (a) and (b) shows that signal level distribution of reverberation is mostly the same as a few seconds ago. But Fig.7 (c) shows that it's a completely different shape after 60 seconds.

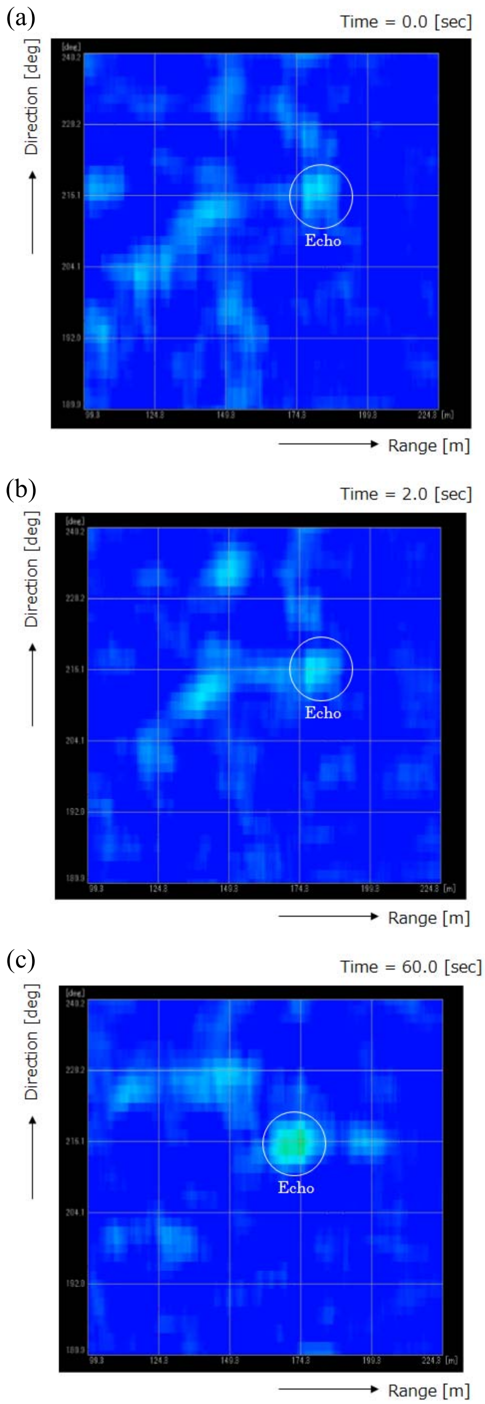


Fig.7 Signal level distribution (a) Time : 0 [sec] (b) Time : 2 [sec] (c) Time : 60 [sec]

Like general surveillance camera, a background image will be extracted. And we will detect the moving object by subtract difference between the background image and the current image. We thought that if we can simulate a changing background image model of noise and reverberation, we can detect the moving object. Here, we tried to apply deep learning to the background image model. Fig.8 shows a diagram of algorithm using deep learning.

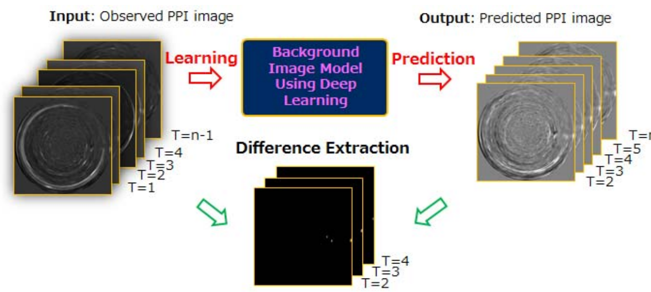


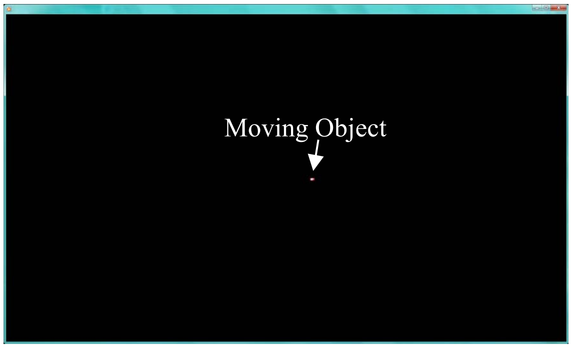
Fig.8 Diagram of algorithm using deep learning

First, The background image model is learned observed plan position indication, in short PPI images of noise and reverberation by using deep learning, not including echo. Our deep learning uses convolutional neural network, in short CNN, which is consist of four layers encoders and four layers decoders with attention mechanism.

After learning, the algorithm detects moving objects, which employs the differences between i) the observed current PPI image and ii) the predicted PPI image generated by deep learning as a background image. Our proposed algorithm becomes the new detection method to decrease the false alarms rate.

Fig.9 shows results of PPI image of difference extraction using our proposed algorithm. Fig.9 (a) shows that the algorithm could detect only moving object. But Fig.9 (b) shows there may be case that false alarms are detect. We are looking forward to removing of these false alarms by next process, a target tracking processing using MHT. MHT will be able to eliminate these false alarms by comparing the plausibility as a moving truck. In this future work, we are going to challenge improvement of this algorithm to adapt in any water environment as a next step.

(a)



(b)

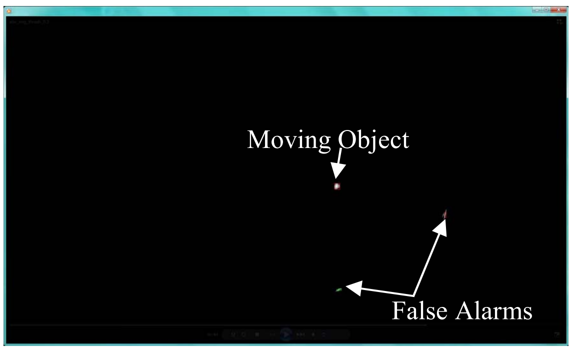


Fig.9 Results of plan position indication, PPI image using our proposed algorithm (a) the case of detection of only moving object (b) the case that false alarms happen

V. CONCLUSIONS

In this work, we have developed the moving object detection method using deep learning because there may be case that it is difficult to combine good reducing false alarms and good detection performance by a statistical analytic method. In this future work, we are going to challenge improvement of this algorithm to adapt in any water environment as a next step. As this method will be good at adapting to diurnal and seasonal variation of the sea environment due, we are looking forward to application to other sonar systems.

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