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A Concept of Coastal Sea Monitoring System from Sky to Water

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Abstract - In this paper, at first, we show our recent monitoring result using a multi-copter at Miho Island's beach as an example of Japanese coastal beach erosion. Comparing two videos in 2016 and 2017, we found massive sand can be easily washed away by only one typhoon and making artificial beach by putting sand for ten years proved to be failed. We also found wave dissipating blocks didn't work well. From this experience, we felt strong demand to develop a new device which we can monitor the coastal area from sky to underwater. So in this paper, we present a concept of environment monitoring system for coastal sea area. The system consists of multi-copter, unmanned surface vehicle (USV), unmanned underwater vehicle (UUV), and floating LBL system to record UUV's underwater position. The main characteristics of this system is USV and UUV are combined together and a multi-copter transports this USV/UUV system from shore or boat to the site where underwater the monitoring is desired. We call this concept as sky to water system (STW). To verify our STW concept, we designed and fabricated a small ROV and USV which can store the ROV. As the payload of the multi-copter is limited, the combined STW weight must be within its payload. We deployed DJI S1000 multi-copter whose maximum payload was around 80N when we boosted its battery, so the STW system must be fabricated as less than 80N. We conducted an experiment to verify our concept and it succeeded with some lessons learned.

***Keywords*:** Multicopter, Underwater Vehicle, Coastal Sea, Environmental Monitoring, Beach Erosion.

1. Introduction

As the economic growth worldwide is rapid and the population growth in the coastal area is accelerating for these decades, the significance of environmental monitoring of coastal sea area has been increasing. The serious threats are coastal erosion, water pollution, sea level rising or storms and so on. One example in Japan is beach erosion which is a big issue in many Japanese coastal area. It sometimes damages a road along the shore that takes an important role in the rural transportation. As the beach vanished and the shore line approaches to the road, the subsoil under the road that supports the road surface gets damaged so repair construction is needed, which not only causes traffic jam but also pressures government budget. It is also said that the washed away sand from the beach affects badly to fisheries around.

Another example of environmental issue is coral bleaching. As [1] and [2] indicate, it is a worldwide well known issue for these 20 years. As the coral reefs are diverse underwater ecosystems which is often called as "rainforests of the sea", its bleaching means loss of one of the most diverse ecosystems on Earth. There are several causes of coral bleaching depending on its regional environment, like land reclamation or nutrients cut off from land into the sea by a newly constructed road, however, the main reason of the massive bleaching like in the Great Barrier Reef in 2016 is regarded as the elevation of sea temperature due to the global warming. It would be basically true that the water temperature affected the massive death of the coral reefs, however, if there is a tool which enables researchers to investigate more detailed monitoring in the water with wider range and time scale, the mechanism of bleaching can be specified more precisely.

As being mentioned above, the reasons why beach erosion or coral bleaching are increasing has not been specified yet, if large scale and long term monitoring can be performed easier with lower cost, it will help researchers investigate those reasons deeper. For the time being, it seems common that we have to use a ship and divers for this kind of investigation or monitoring underwater, which takes cost for hiring a ship and time for coming from a port to the desired monitoring site, where the port is not always near the site. So handy and low cost monitoring devices should be developed.

When a scientist needs to investigate underwater environment, he or she usually must hire a boat and sometimes need to dive into the sea. If the water depth is more than 30m, the diving time is very limited and if the depth is deeper, it is difficult for them to dive with normal equipments. The area where one person can swim around is also limited even if he or she uses a marine jet or a diving thruster. This limitation in time and space is a kind of bottle neck especially in coral reef investigation. Needless to say, the coral reef area is very large in general. For example, the coral reef area around Japan spreads very widely from Kagoshima bay to near Taiwan area, whose length is around 1200km. The Great Barrier Reef in Australia has more than 344,400km2. So the investigation by divers takes too much time to cover all this area, and it seems very hard for them to make a total map of monitoring record in a certain time as annually.

Satellite images or taking pictures using a small aircraft are effective to cover the wide area as is described in [3], however these methods spend much cost on getting data or hiring the aircraft and cannot take underwater pictures which are essential for precise research. So it is important to develop a low cost technology that can take wide pictures from sky and also can monitor underwater situation simultaneously.

2. Necessity of Long Term Monitoring- From Our Beach Erosion Experience

Beach erosion has been one of the big issues related to coastal management in Japan for at least more than 20 years [6]. There used to be beautiful long beaches near the river mouth of big rivers, which all gone now. It has been said that the construction of upstream dam in a big river stops transportation of massive soil from mountains so that a beach cannot keep its shape while waves are washing away its sand. However, there seems to be no scientific evidence of this story because there is no accumulated data of soil flow for years before the dams were constructed. This implies we better accumulate environmental data or keep monitoring of natural environment as much as possible even if there is no problem for the time being.

One typical place of beach erosion is just in front of our campus as is written in [7]. Our campus is in Miho Island where used to be very famous for its beautiful sand beach. This beach is referred in several Japanese very well-known classical literatures some of which is written more than 1000 years ago, so it is designated as a World Heritage Site in 2015. But rapid and massive beach erosion of the island is one of the critical issues. It is said that UNESCO is warning if the wave dissipating blocks will not be removed, they will cancel the WHS designation because the blocks damage the scenery of the landscape of the coastline of the island. On the other hand, the wave dissipating blocks are essential to keep shore sand from being washed away by waves or currents. There is an important national road Route 150 that faces the shore, and the most important role of these blocks is to keep the road foundation from being washed away to avoid caving and depression.

Hundreds of dump trucks totally have been transporting massive soil to recover the beach for more than 10 years as far as I observed. In addition, many wave dissipating blocks have been put as shown in Fig.1. However, we recently realized that these efforts have not been paid off and it might be possible a lot of taxpayers' money have been lost. But this is just our feeling and there is no quantitative evidence to prove that the wave dissipating blocks are meaningless.

This is one of our strong motivations to develop a new handy monitoring system. We started test monitoring using

Fig. 1: Wave dissipating blocks along KUNO beach in MIHO Island.

a multi-copter and soon found it is very effective but need to be monitored underwater simultaneously [5].

Fig.2 shows the beach in front of our campus on Oct. 26th in 2016. These pictures are taken by a multi-copter. As we can see from these pictures, the sand had washed away but still remained like a cliff. The height was around 3m and the distance from the cliff ridge to the fence was around 30m. Fig.1 and Fig.3 show the beach on Oct 31st in 2017. On Oct. 29th, we had a very big typhoon which passed through this area. After that, as we foresaw, a large part of the beach washed away as we can see in those pictures. Fig.3 shows the former artificial mound all vanished from the fence of a walk along. In addtition, a kind of foundation structure to support this artificial mound showed up. As shown in Fig.4, we can estimate an target area in the picture using a typical distance (117.8m) between point A and B, so if we can measure distributions of water depth in this area, we can estimate the amount of lost sand.

This place is just 5 minutes' walk from our campus but it takes around 1 hour if we hire a boat. From this experience, and considering how easy it is to bring the system from the shore instead of hiring a boat, we learned the necessity of developing a new monitoring system which can be used from sky to water as portable as possible.

Fig. 2: Mound remained on Oct. 26th in 2016.

Fig. 3: Mound washed away by waves after a big typhoon on Oct 31st in 2017.

3. Sky to Water Concept

Fig.5 shows our sky to water (STW) concept. The system consists of a multi-copter for system transportation, multi-copters for taking pictures from the sky (omitted in this picture), an unmanned surface vehicle, a ROV or AUV and at least three floating LBL bases. Each module is delivered by the multi-copter from a mother vessel or seashore. The ROV is docked to the unmanned surface vehicle (USV) when the multi-copter transports it. The USV has wireless LAN so that we can control the USV and ROV remotely and monitor the underwater images which the ROV films by its video camera. The USV also equips a kind of winch system to release and wind up the umbilical cable attached to the ROV. If an AUV is deployed, the winch system can be omitted. The buoy has ultrasound ranging module, GPS and communication device (XBee module). The communication device is used to synchronize all timers attached to each buoy and to communicate between each buoy for transmission of acquired data to calculate the base line distance or underwater coordinate of the ROV or AUV.

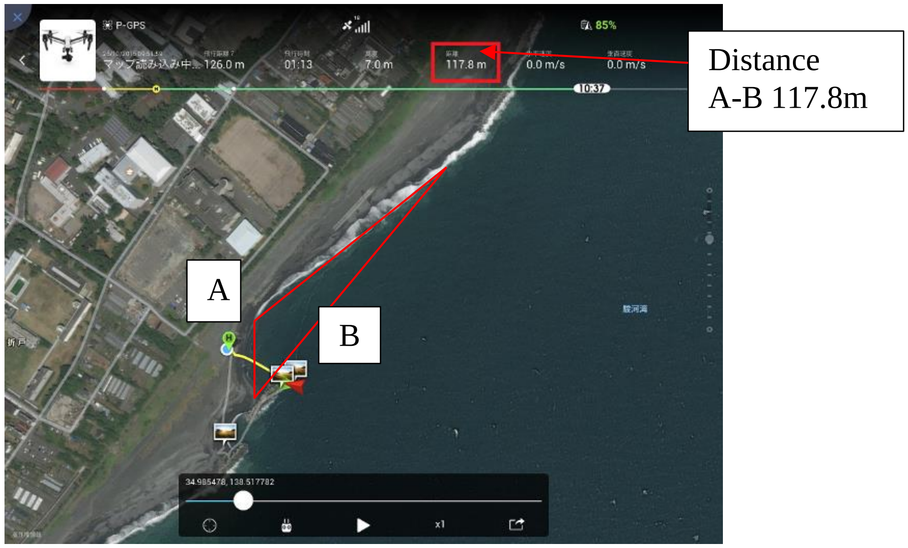

Fig. 4: Vanished area estimation from a picture.

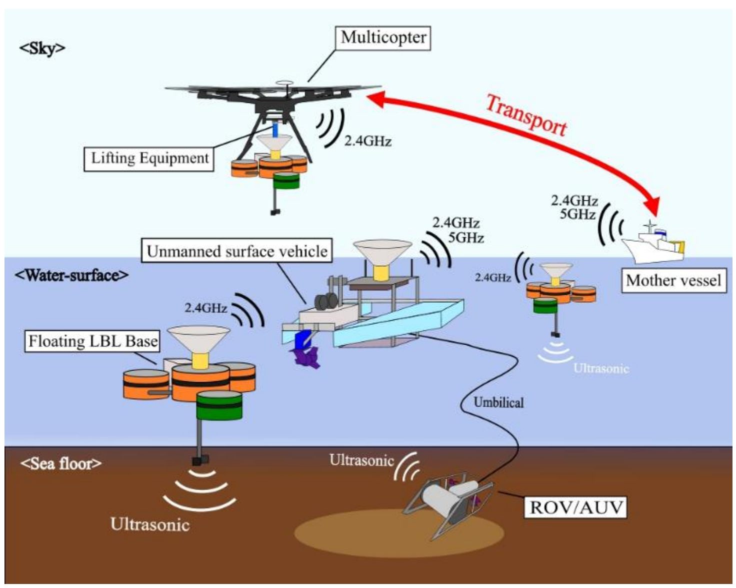

Fig. 5: Conceptual view of sky to water monitoring system.

3.1. Floating LBL

Determination of underwater coordinates is important in environment monitoring. In commercial application like offshore oil/gas development, LBL or SSBL are common to measure underwater coordinate. But SSBL cannot be used if the water depth is very shallow, and fixing LBL baseline on the sea bottom is not an easy task. In some scientific or academic operations, the project budget is very limited so a low cost position detection system should be developed. In the coral reef monitoring operation, we need to take underwater pictures to record and monitor the condition of the reefs. In that case, we need underwater coordinates where the picture is taken. Then we can make an underwater map of the total reef condition using from the sky pictures. The floating LBL system will help this job.

The floating LBL system consists of at least 3 buoys. Each of that has a pair of ultrasound receiver and transmitter. A buoy also has a set of Xbee wireless communication device to make a serial communication with other buoys. A GPS unit is attached on each buoy. The master buoy is the origin of the coordinate and controls the total system. The detailed concept of our floating LBL is written in [4]. To make the LBL system cheaper, we fabricated a set of ultrasound ranging module by ourselves. The calibration experiment is done in the sea. As shown in Fig.6 and from our tank test, we confirmed it can measure the distance from 0.3m to 30m.

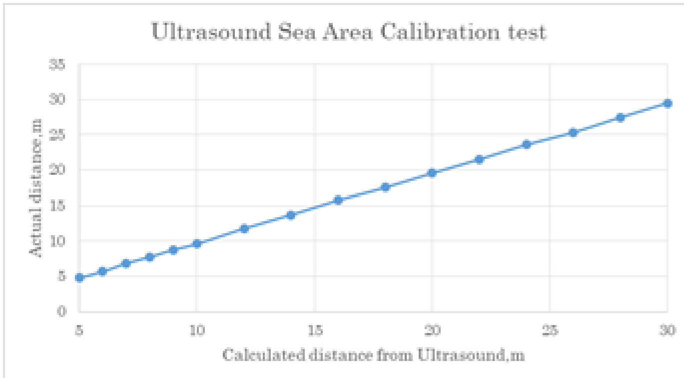

Fig. 6: Calibration result of ultrasound ranging module in the sea.

3.2. USV (Unmanned Surface Vehicle)

Fig.7 shows the USV catamaran we designed. As the figure shows, the UUV (in this case ROV) is stored in the garage of USV. The main features and functions of the USV are as follows.

- Provide docking space for the UUV in transportation, launch and recovery
- Provide a wireless connection from UUV to the control centre on land or boat
- Deploy and navigate UUV to desired place after released from multi-copter
- Provide real time GPS location (reference origin of underwater coordinate in the floating LBL)

ROV is stored inside catamaran and become one set of structure. It makes the job easier when transporting the device to the desired places.

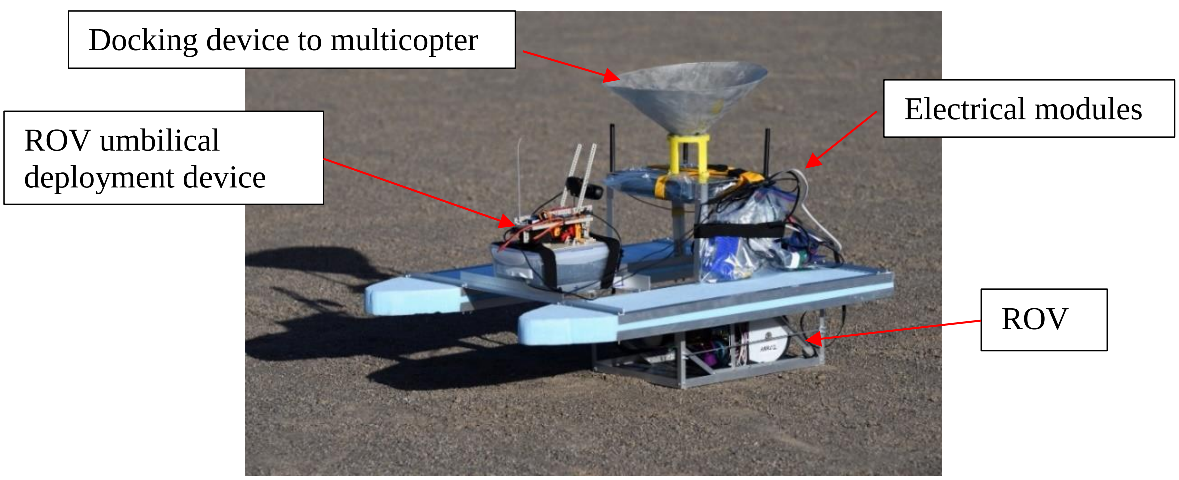

Fig. 7: USV system which is used for UUV launch and recovery.

The equipment on board of the catamaran system consists of wireless LAN, battery module, ROV tether control device, camera system to monitor the ROV in/out, GPS, an azimuth thruster that control the USV position and RaspberryPi computer to integrate the total system. The USV is a very important interface between UUV and the researcher on the sea. The remote control of the USV and the UUV is performed through the wireless LAN and the operator can also check the underwater images. The total weight of the USV including ROV became 85N finally. At first, the USV is fabricated bigger, but we found that the deck of the USV interrupts the thrust force of the multi-copter, so we reconsidered its size not to interrupt the flow of air of the propellers.

3.3. Small ROV

Fig.8 shows our small ROV “ANKOU-2”. ANKOU means an anglerfish in Japanese. The total weight is around 50N. The designed maximum water depth is estimated as 100m, however we only tested 65m. It has four thrusters whose propeller is designed and fabricated in our laboratory using 3D printer. It has two pressure hulls. In the main pressure hull, there are computer system (beagle bone board), thruster controller, and underwater video camera. There is a lithium polymer battery inside the other hull. The PLC module is inside the main hull and the control signal for remote operation is coming down through the umbilical cable from the wireless LAN on the USV.

From the viewpoint of the payload of the multi-copter, it is desirable that the ROV weight should be lighter. On the other hand, if the ROV is too small, its maneuverability becomes worse. We discussed this matter and tested several models in our tank then decided the size. We need to investigate further about the optimization of the size of the ROV considering the environmental condition of the desired monitoring site.

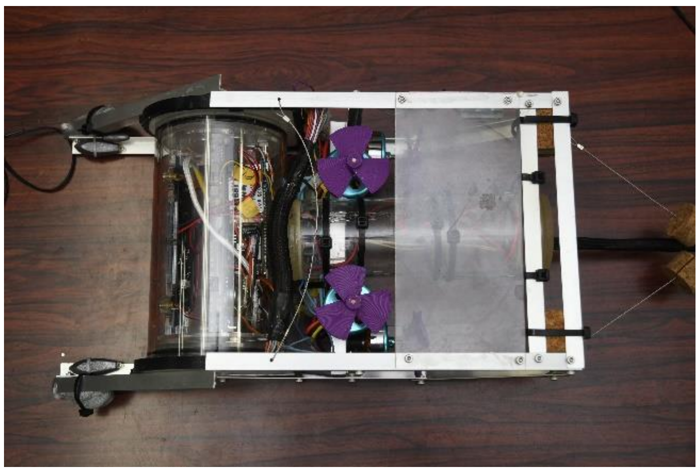

Fig. 8: Small ROV “ANKOU-2”.

4. Experiment to Check the Sky to Water Concept

To confirm all the system we fabricated and programed, we tried sea trial from our university’s pier in Shimizu Miho area. We succeeded the transportation of the USV with ROV from the pier to the sea as shown in Fig.9.

In the experiment, at first the multicopter flied to the USV on the pier and docking procedure is successfully done. Subsequently, the multi-copter lifted the USV and it flies to the sea surface to put down the USV on the sea surface. Then it released the USV. After that, the ROV launched from the USV and swam around into the sea as shown in Fig.10. Fig.11 shows one of the underwater pictures which we were monitoring on the pier. The underwater images successfully transmitted through USV system. Finally the USV wound up the ROV successfully to be docked back in the garage.

After the ROV and USV docked, we tried to recover the system back to the pier by docking the multicopter to the USV. Although the multicopter docked the funnel of the USV successfully on the sea, it couldn’t lift the system up due to water resistance of the garage floor where the ROV was put on. This is because the payload of the multicopter was beyond its maximum. So we need to reduce the total weight or prepare more powerful multicopter than S1000. This is also our important future work and lessons learned. Images from Fig.9, Fig.10 and Fig.12 are taken using another multicopter which is specialized to photographing from the sky.

Fig. 9: Multicopter delivers USV from the pier to the sea.

Fig. 10: ROV launched from USV.

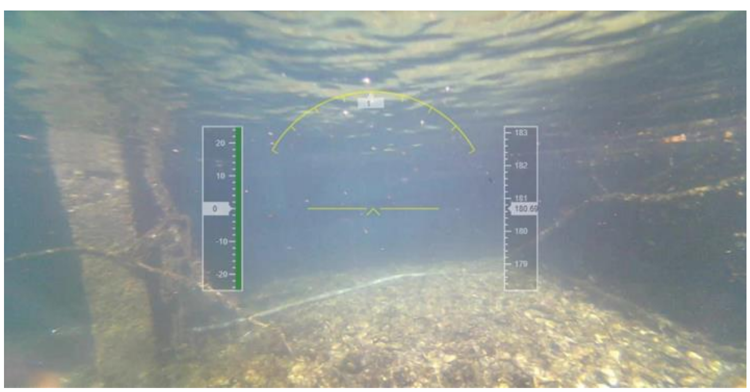

Fig. 11: Underwater image taken by the ROV (pier's underwater structure).

5. Conclusion

In this paper, we discussed the necessity of new monitoring device for coastal sea environment based on our experience of monitoring test of beach erosion using a multi-copter. Although the multi-copter is a powerful tool for our purpose, we needed to add underwater monitoring function. So we presented a new concept of environmental monitoring system for coastal sea area using multi-copter and underwater robot, which we call sky to water system. The heavy duty multi-copter is used to deliver the underwater monitoring system. We also fabricated a USV as an interface platform which connects underwater system to researchers on the sea surface. A small ROV is designed and fabricated, too. The ROV is stored in a kind of garage under the deck of the USV. We developed a light weight umbilical cable handling system which releases or winds up the cable in accordance with the motion of the ROV. The docking device between the multi-copter and the USV is also developed. Ultrasound ranging system which is used for the floating LBL to calculate the underwater position is completed. The sea trial to verify the total system is performed from our university's pier and succeeded with some lessons learned. The total system is successfully transported by the multi-copter. ROV launch from USV and recovery to USV are performed very well. The USV recovery from the sea and underwater position detection is our next step.

Fig. 12: Recovery from the sea is failed due to lack of payload of the multi-copter.

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