

Ocean Outfall Mapping Using an Autonomous Underwater Vehicle

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Abstract—Ocean outfalls are difficult to observe and the traditional monitoring methods are expensive and can only provide limited information. As an alternative, Autonomous Underwater Vehicles (AUVs) have proved to be an effective tool for outfall mapping. This paper describes an outfall mapping mission by the *MUN Explorer AUV* off the east coast of Canada. A submerged freshwater outfall with Rhodamine WT dye was discharged into a bay and the *MUN Explorer AUV* equipped with a fluorometer was used to measure the dye concentration and the extent of the dispersed plume. The results have shown that the AUV can be effectively used to map the outfall and future work is needed to provide more detailed plume information.

I. INTRODUCTION

Scientists world wide are interested in monitoring ocean outfalls to assess their characteristics in what are often harsh marine environments. Several field studies have been conducted to map both sewage outfalls and industrial outfalls such as produced water outfalls. For example, Smith et al. [1] monitored a produced water outfall using a suction hose array and also by collecting samples using hand-held sampling bottles by a diver. Vessel-based tow-yo experiments have also been widely used [2] [3] [4] [5]. The traditional methods used in the above studies are generally very expensive and time consuming and can only provide very limited information. It is noted that increasing water depth also increases the level of sampling error due to the drift of surface vessel platforms and prolonged sampling times. Furthermore, traditional monitoring techniques cannot account for the dynamics of the ocean environment. Therefore, new and innovative means of outfall mapping methods are needed.

Autonomous Underwater Vehicles (AUVs) are a new generation of autonomous oceanographic platform that are capable of tracking water masses, and recording chemical/physical/biological properties in the ocean. The recent use of AUVs in a wide range of applications has shown their potential as a mobile sensor in ocean outfall mapping. For ocean outfall monitoring and plume tracking applications, several studies [6] [7] [8] using the REMUS class AUV and one study [9] using the ARCS class AUV have been reported.

Memorial University of Newfoundland has recently acquired a new *Explorer* class AUV built by International Submarine Engineering Ltd. The first operational mission took place in August 2006, in Holyrood Bay off the east coast of Newfoundland, Canada. This paper presents the results obtained from an ocean outfall mapping mission.

The paper is organized as follows. In section II, a short description of the *MUN Explorer AUV* is presented. Then the study sites and the experimental setup are described in section III. The experimental results are reported in section IV and the conclusions and future work are discussed in section V.

II. THE *MUN EXPLORER* AUV

The *MUN Explorer AUV* is a 4.5m ocean-going instrumentation platform with a 3,000m depth capability (see Figure 1). The strength of the *MUN Explorer AUV* is its ability to carry 150kg of scientific payload (instruments), with a power requirement in the hundreds of Watts, on missions of up to 12 hours duration or 100 km. The mission length drops as power requirement increases. The detailed specifications of the *MUN Explorer AUV* are listed in Table I.

The *MUN Explorer* is designed such that the whole of the fore end is available for the carriage of different sensors for different types of research missions. Apart from the pressure hull which houses the batteries, control hardware, and navigation systems, the AUV is freely flooded. The fore section casing consists of a relatively low cost fibreglass shell. For complicated instrumentation outfits, the instruments can be installed in their own dedicated instrumentation section shell piece. Different users can be provided with an instrumentation section shell piece in order to outfit their instruments, thus making efficient use of the AUV time and availability for missions.

The *MUN Explorer* has a Vehicle Control Computer (VCC) which is housed inside a pressure hull in the middle of the vehicle. The VCC collects data from all the instruments and controls the execution of missions. This computer can remotely communicate with a Surface Control Console (SCC) while it is on the surface. The SCC transmits pilot commands

to the VCC and creates graphical displays to provide information to the operator. Before the AUV is put in the water, missions are planned on the Mission Planning Workstation and uploaded into the VCC. Once in the water and the mission is started, the vehicle follows the pre-planned routes and depths and collects data. After a mission is completed, the vehicle returns to a pre-programmed location.

TABLE I
SPECIFICATIONS OF *MUN EXPLORER*

Characteristics	Specifications
Length	4.5 m
Hull Diameter	0.69 m
Dry Weight	650 kg
Displacement	660 kg
Maximum Depth	3000 m
Speed Range	0.5 m to 2.5 m/s
Payload	Without removing trim lead - 150 kg
Turning Radius	10 m
Sensors	MicroCTD, Idronaut dissolved oxygen, Cyclops-7 RWT fluorometer
Navigation	<ul style="list-style-type: none"> Watson BA 303 AHRS Sound Ocean System GPS with retractable mast. RDI Workhorse 300 kHz DVL Paroscientific dept transducer with an accuracy of 0.1% over the 3000m range. Kongsberg Simrad Mesotech 1007 Digital Altimeter
Emergency Equipment	ORE 4336B Transponder locator, NovatechST-AR400 Strobe, RF 700 A1 Radio Beacon

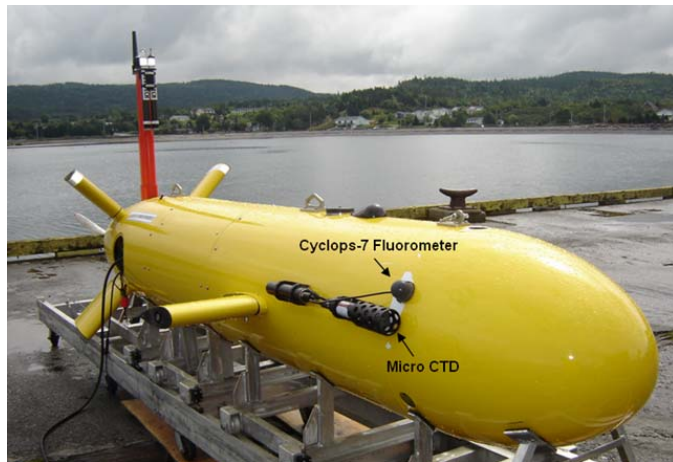


Figure 1. *MUN Explorer* AUV with CTD/Fluorometer sensor.

III. THE STUDY SITE AND EXPERIMENTAL SETUP

The field tests were performed in the south arm of Holyrood Bay at the head of Conception Bay ($47^{\circ}23'16.27''$ N, $53^{\circ}07'59.32''$ W). Holyrood Bay is located about 40 km southwest of St. John's, Newfoundland. The location and bathymetry of the study area is shown in Figure 2.

The AUV was launched from the wharf on the west side of the Bay. The water depth at the wharf is about 6 m. Except for the locations close to coastline, the water depths for most of

the study area are deeper than 6 m. The deepest point of about 19 m is at the center of the Bay.

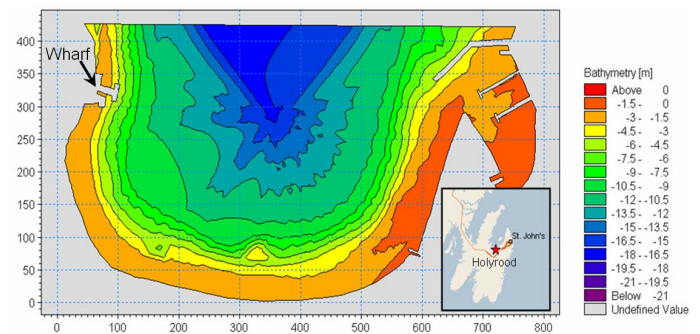


Figure 2. Location and bathymetry of the study site.

There was no existing outfall at the study area and an outfall was built for the purpose of experiment. A storage tank with a continuous supply of freshwater was used as the source of discharge. The tank had a 2-in diameter outflow pipe which was submerged at about 3 m below the sea surface. To make the outfall traceable, Rhodamine WT dye was used. The dye was mixed with the source before discharge and the effluent concentration was about 11.5 ppm for the mission on Aug 31, 2006. During the experiment, the discharge was started at least two hours earlier than the launching of the AUV to give enough time for the plume to stabilize and disperse. The vehicle was then launched and the dye concentration was monitored by a Turner design Cyclops-7 fluorometer. Salinity and temperature data were also collected by the AUV with a Applied Microsystems MicroCTD 7163 (see Figure 1).

The vehicle speed was 1.5 m/s during the mission. The vehicle data, including the position, heading, speeds etc, were logged to the vehicle computer at a sampling rate of 0.1 s. The CTD and fluorometer had a separate datalogger and was synchronized with the vehicle time before the mission. The sampling interval of the CTD/fluorometer was 0.2 s (5 data points per second). This setup yielded a horizontal resolution of 30 cm along the AUV trajectory.

IV. RESULTS AND DISCUSSION

The mission time for this test was about 2 hours. The vehicle surveyed an area of about $120 \text{ m} \times 240 \text{ m}$. The vehicle trajectories over the course of the test are shown in Figure 3. It can be seen from the figure that there is an overlap of the trajectory and the wharf. There are two possible reasons for this deviation of trajectory: error of the GPS and error of the map. Between these two possible error sources, it is more likely that this is due to the error of the GPS. A GPS for civilian usage generally has an error of about 10 m and this is about the error level observed in Figure 3. As the trajectory is consistent throughout the mission, this bias was treated as a system error and was corrected during the later construction of the contour plot.

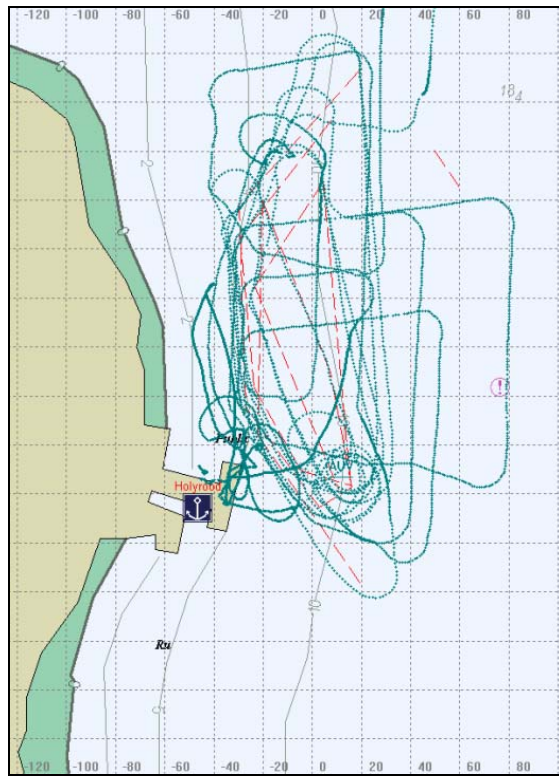


Figure 3. Trajectory of the AUV shown by the FleetManager software (August 31, 2006).

The area survey for this test was mainly east and northeast of the wharf. This was the projected plume direction based on the observation of drift of surface floats. This direction was lately confirmed by the currents measured from a current meter moored about 10 m away from the discharge point.

The depths of the AUV missions over time are shown in Figure 4. While most of the time the AUV was operated in the upper 1.2 m of the water column, two brief dives to 3 m depth were also made.

The measured concentrations over the course of the test are plotted in Figure 5. It can be seen that the measured concentrations for the study area range from 0 to about 273 ppb. By matching the time of Figures 4 and 5, the highest concentration was observed at around 15:12:40 at about 0.47 m depth. This can be confirmed by plotting the concentration versus depth of the AUV (see Figure 6). It can be seen from Figure 6 that the majority of the Rhodamine is in the 0.5 m layer. For the 3 m layer surveyed, the concentrations range from 0 to about 80 ppb.

As fewer data were collected for layers deeper than 0.5m, only the data at 0.5 m layer were used to construct the contour plots. It can be seen from the contour plots (Figure 7) that the AUV was able to map the overall picture of the plume. The plume spread out in the mean current direction - northeast. The highest concentration was measured at the discharge point and this decreased towards the plume edge. Similarly to the plume mapping tests conducted using a traditional towing method [3] [4] [5], the plume mapped by the AUV is not

smooth. For example, two patches were shown on the north and east edges of the plume.

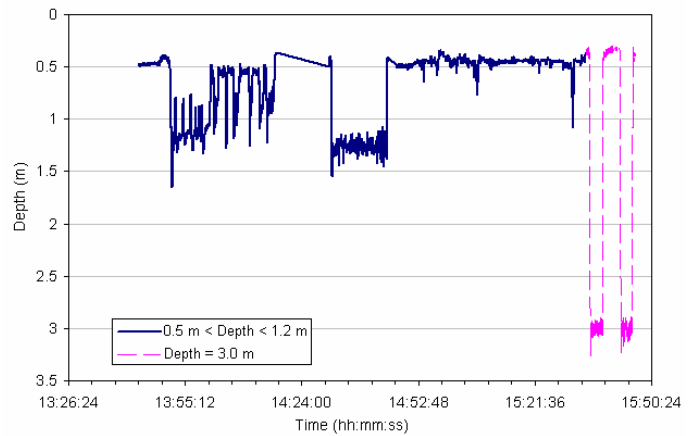


Figure 4. Time series plot of the AUV depth (August 31, 2006).

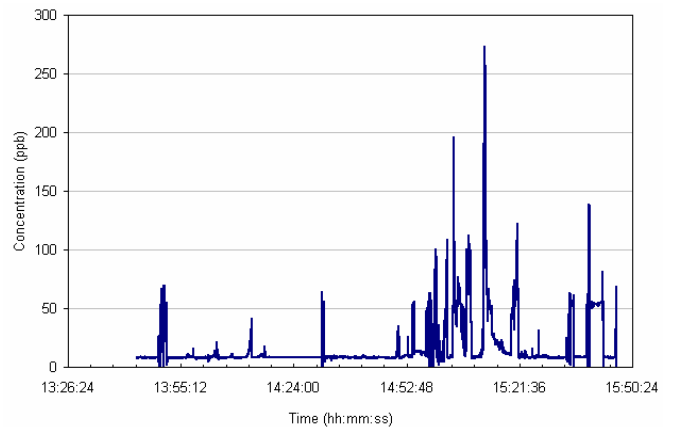


Figure 5. Time series plot of the Rhodamine WT concentration.

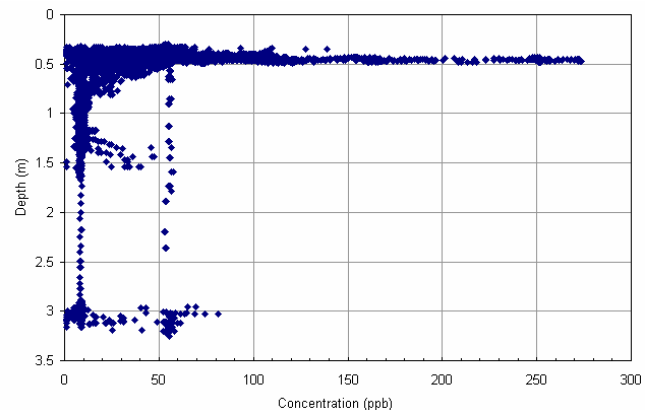


Figure 6. Rhodamine WT concentration versus AUV depth.

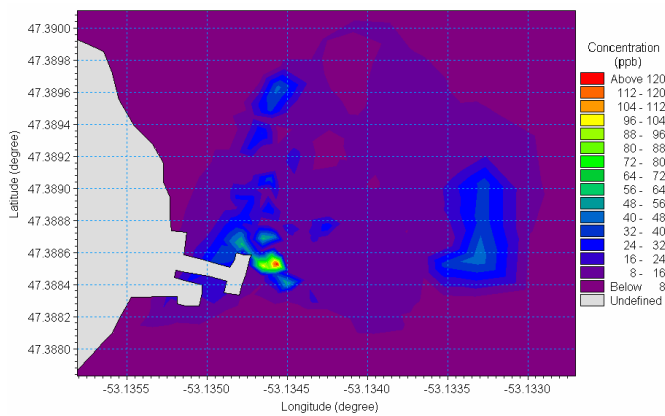


Figure 7. Rhodamine WT concentration versus AUV depth.

V. EXPERIENCE GAINED AND FUTURE WORK

In this study, the *MUN Explorer* was used to map a freshwater plume in Holyrood Bay. As this was the first plume mapping mission using this AUV, only a simple mission was performed. In order to map the plume more effectively and improve the quality of experiments in the future, the following methods are suggested:

- The survey area should be large enough to capture the plume edge. If the farthest points have values greater than zero, the contour beyond these points will be difficult to construct. This was a problem encountered in the present study and an arbitrary edge far away from the plume was assumed.
- It is suggested that the sensors are mounted on the bottom of the AUV instead of the side. The reason is that during some surface missions especially in windy conditions, the sensor may be out of water when the vehicle is trying to maintain position. In these cases, zero values will be collected and these represent spurious readings that affect the data quality.
- For the same reason, the AUV dive depth should be at least 0.7 m if the sensor mounting is to remain unchanged.
- The present survey only mapped one horizontal layer and the capabilities of the AUV were not fully used. A longer mission that continually surveyed multi-layers is suggested in order to obtain 3D information of the plume.

- Due to the separate data logging systems (vehicle position and sensor data), the post-processing was extremely time-consuming. The sensor should be integrated with the vehicle and log the data in the same file. This upgrade has already been completed.

ACKNOWLEDGMENT

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