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Challenges to implementing a ballast water remote monitoring system

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A B S T R A C T

In this paper, we describe a ballast water data logger system to monitor the ballast water exchange and the water quality contained in ship tanks. This system is able to register physical-chemical parameters of ballast water by using sensors for measuring turbidity, salinity, dissolved oxygen, pH and temperature. Those data are tagged with the geographical position (GPS), date and time at which the ship operates its ballast system and are remotely transferred via satellite transmission to an Internet server. The system was installed on the ship *M/V Crateus* (from Norsul Navigation Company) and has been functioning since April 2014, collecting ballast water quality parameters in the routes between Argentina and the north region of Brazil. From the collected data, the system proved to be able to identify the ballast water exchange along the ship's journey, allowing for independent verification of information provided by the crew in the ballast water reporting form. As an additional advantage, this information can be automatically transmitted to the port authorities, improving the reliability of this information and reducing, or even removing, the possibility of data tampering. Nowadays, the salinity is the main indicator to determinate whether a ship makes the ballast water exchange. However, we identify that water turbidity can be one more indicator to identify the ballast water exchange that could be recommended by the International Maritime Organization.

1. Introduction

The introduction of exotic species in port areas is currently a great environmental problem in several parts of the world (Cohen, 1998; Cohen and Foster, 2010; Pereira and Brinati, 2012), and this was first reported by the International Maritime Organization (IMO) in 1973 during the creation of the International Convention for the Prevention of Pollution from Ships - MARPOL 73/78 (IMO, 2004; Cohen and Foster, 2010). In the course of the convention, Resolution 18 for Research into the Effects of Discharge of Ballast Water containing Bacteria of Epidemic Diseases was approved, which charged the IMO with the responsibility for elaborating measures of ballast water (BW) control (Cohen, 1998). In fact, since 1994, several exotic species have been identified in many parts of the world (Hallegraeff, 1992; Carlton and Geller, 1993; Gollasch, 2006), and studies have identified BW as the vector of exotic species transfer (Ruiz et al., 1997). Therefore, the impact caused by the organisms found in BW, such as *Vibrio cholerae* (Dobroski et al., 2009; Cohen and Dobbs, 2015), can be of great important for marine environment, the economy and human health.

The first initiative taken by the IMO to deal with this problem was to establish Resolution A.868 (20) in 1997, which recommends that ships perform ballast water exchange (BWE) in open sea. In 2004, the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention) took place, with the purpose of establishing guidelines for BW control (IMO, 2004).

BW operations normally occur while ships are unloading cargo in ports. In the port regions, the salinity varies between 32 ppt and 35 ppt (parts per trillion), although it can be higher or lower in some specific cases (Murphy et al., 2008; Doblin et al., 2010; Cohen and Foster, 2010). On the other side, in open ocean, the salinity varies, on average, from 35 ppt to 37 ppt (Murphy et al., 2008). Thus,

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the BWE suggests that fresh water organisms cannot survive in salt water and vice-versa (Smith et al., 1999). So, BWE typically eliminates between 70% and 99% of the organisms originally taken into a tank while the vessel is in or near a port (Cohen, 1998). However, in order to have a proof of the effectiveness of mid-ocean exchange, the BW salinity must be examined. This test consists of collecting a sample of the BW in the tank, dripping it in a refractometer or using an electronic meter and analyzing the salinity and specific weight of the sample. The result will confirm if the water collected originates from estuary, coastal or mid-ocean waters and will confirm whether this water was exchanged in the open s ea.

Current methods to verify the real exchange of BW at conditions established by the BWM Convention are limited to determining the salinity (Duggan et al., 2005; Drake et al., 2002; Choi et al., 2005), whilst it would be convenient if other parameters were also verified. For an onboard verification, tanks have to be opened and samples collected (Gray et al., 2007), but there are many reported problems concerning tank opening operations (Murphy et al., 2003), such as the lack of inspection stations, as well as the lack of specialized technicians to perform them. Another problem, although not yet reported in the literature, involves the team mobilization cost for this procedure. Alternatively, another method for this verification is to use the coordinates submitted in the BW reporting forms (BWRFs). From these reports, it is possible to identify if the region of the BWE was at least 200 nautical miles away from the coast and in waters at least 200 m (m) deep, the basic demands for the exchange of BW (Pereira et al., 2014).

On the other hand, there is a problem associated with the reliability of the information in the BWRFs that the ships have to deliver to the Port State Control (PSC) before arriving at a port (Pereira et al., 2014). In fact, in the specific case of Brazil, records of BWE violations are not uncommon. Leal Neto (2007) presented the main problems found in a survey conducted by the Globallast Program, using forms delivered to the Brazilian Navy between 2001 and 2002. Caron Junior (2007) showed inconsistencies during the analyses of 808 BW forms handed to maritime authorities of the port of Itajaí-SC, in the south of Brazil. The Brazilian Health Surveillance Agency (2003) conducted another study that shows the results of 99 samples of BW in 9 Brazilian ports, revealing that some ships had not exchanged the BW. However, the lack of confidence of BWE also affects other countries. In fact, Brown (2012) showed the non-compliance BW report in California. In the first semester of 2012, approximately 1 million metric tons (MMT) non-compliance BW was discharged in California ports, due to either operational error or incorrect geography and not to intentional mismanagement. In 2014, all ships that accessed the Great Lakes had their tanks examined and BW samples were collected (Great Lakes Seaway, 2015). Pereira et al. (2014) presented several problems with BWRFs delivered by ships to the Brazilian Navy in the Amazon region, where it was identified that ships deballast in ports in this region without conducting the BWE at sea. Additionally, it was identified that these ships presented problems with the quality of the BW inside their tanks.

Generally speaking, the BWRF does not provide information about the quality of the BW captured by the ships. However, information of water characteristics, such as turbidity, salinity, dissolved oxygen (DO), pH and temperature, would be very useful for the PSC to identify the quality of the water, especially because the water collected in the ports may contain domestic, industrial and agricultural effluents (Vandermeulen, 1996; Peterlin et al., 2005). These water parameters can indicate the probability of surviving species and treatment efficiency of the BW inside ship tanks. In fact, some of these effluents may be highly polluting when discharged in nature in the destination port environment. Among these constituents of estuary waters can be found dissolved solids, salts, organic sewage, nutrients, heavy metals, hydrocarbons, radioactive materials and herbicides (Clark, 1986) that are not identified with current methods utilized to evaluate the quality of BW. Mainly, the release of sewage into port regions can alter the pH and the demand for DO in water, carrying the nutrients and promoting the proliferation of toxic algae and the destabilization of the aquatic ecosystem (Morrison et al., 2001).

In environments with high concentrations of organic matter, such as algae, turbidity can be changed (Torgan, 2011). These organic matters can be transferred into the BW tanks and can cause problems such as red tide when discharged in other environments. The change in turbidity can also occur in the presence of solid "sand" in suspension (Prange and Pereira, 2013). The presence of dissolved solids in the sea water tends to be higher than in estuaries due to the low sea depth. Therefore, it is possible to find a large amount of sand at the bottom of BW tanks (Prange and Pereira, 2013). Thus, the turbidity is indicative of the presence of several organic and inorganic components that may be present in the BW captured by the ship.

Since salinity may change from port to port, monitoring this parameter may indicate whether there are risks of transfer species due to the similarity between origin and destination ports. Other factors associated with environmental similarity are water pH and temperature, which can significantly impact the survival and stability of toxins produced by many organisms (Torgan, 2011). Thus, the variation in the pH of the water collected and the water exchanged by the ship can be an indicative of the probability of surviving species in the ballast tanks. Besides, the presence of dissolved gases in the BW can also indicate the probability of surviving organisms and is related to the water temperature (Jewett et al., 2005). For example, there are certain ranges of dissolved oxygen (DO) in water (mg/l) that can be translated into survivability of species. So, low DO levels are responsible for the death of many organisms in BW (Tamburri et al., 2002).

As can be seen, in spite of the importance of different water quality parameters to understand the effectiveness of BWE process, only the salinity is evaluated when ships arrive at the port and undergo BW inspection, with no other parameters reported by ships in BWRFs. So, motivated by this, in this paper, we develop a BW remote monitoring system (BWRMS) that collects, in real time and directly inside the ballast tanks, the BW quality parameters. This system includes sensors for turbidity, conductivity (salinity), dissolved oxygen (DO), pH and temperature. An important characteristic of this monitoring system is that the data from the sensors are tagged with the ship's geographical position and the date and time of the collection. The data are recorded in an unchangeable electronic controller unit and remotely transferred via satellite to an inland web server, where they can be analyzed. In that way, the system allows not just monitoring and analyzation of the evolution of water quality parameters but also independent verification of the geographical position where the BW is exchanged. This can be done from the variations observed in the data collected from sensors. Note that since the collected data are automatically transmitted, the relevant information can be directly sent to the port authority to validate the information in the BWRF, improving its reliability and reducing or even removing the possibility of data tampering. Even more, this can be the starting point for a new type of electronic BW reporting form (e-BWRF).

This system was installed on the ship *M/V Norsul Crateus* (from Norsul navigation company of Brazil) and has been in function since April 2014, collecting BW parameters in the routes between the ports located in South America (Argentina) and Brazil. In this paper, we will present the validation of the system considering the data from all voyages realized by the ship during the time between April 2014 and December 2015, where it is possible to compare the data