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Preparing the automatic spill recovery by two unmanned boats towing a boom: Development with scale experiments

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ABSTRACT

The menace of floating spills is frequently solved using a team of ships towing a boom. This operation involves specific control and coordination aspects. Some automatic advice, on board the ships, could be helpful for the pilots. Moreover, it could be convenient to have the alternative of using unmanned boats, especially if the spill represents a danger for humans. This paper studies the control and coordination needs for automatically towing a boom, and proposes the use of unmanned boats with autonomous control. The research is supported by simulations and experiments with scaled boats towing a boom. Promising results have been obtained.

1. Introduction

The motivation of this work is related to an environmental catastrophe that happened when the ship named 'Prestige' sank near North-West Spain, throwing large quantities of crude oil to the sea, and spoiling the coast along hundreds of kilometers. From time to time, TV reports showed opportunity teams of fisher's ships towing booms. From our point of view, it seemed to be not an easy task, and we decided to build two scaled ships and to experimentally study what might happen. Based on this study, our desire was to finally arrive to fully automated recovery operations using unmanned boats or ships.

From years ago our research focused on translating mobile robotics techniques to ships on an experimental basis. Three autonomy levels were contemplated: to have a human pilot on board, to have a remotely operated unmanned ship, or to have an autonomous unmanned ship. The use of scaled ships for the last two levels is very convenient for experimental work. In case of human on board, some degree of collaboration between human intervention and automated operation could be established, the mildest automation contribution could be to offer just an advising system to the pilot. In any case, it is useful to consider the most exigent level. Therefore, the target considered in our research is to devise autonomous unmanned vehicles for the boom towing operations. This kind of marine vehicle is denoted in this article as ASV (autonomous surface vehicle).

Fig. 1 illustrates the kind of operation to be automatically performed.

Our experimental system has two ASVs and a ground station. Through a digital radio link the ground station can interrupt the autonomous behavior of the vehicles, and then be used for remote control when opportune. However this is unusual. Normally, the ground station is used for sending waypoints or other behavior specifications to the ships, before the actual operation starts, and then it remains in passive mode, just receiving data from the ships.

The operation is automatically planned before start. The system only needs information on three positions: origin, floating spill, and final destination.

Once the operation starts, the ASVs tow the boom towards the objective, minimizing the towing effort, near the objective the ASVs deploy and advance, and finally get closer, confining the spill; then the formation moves towards the destination. It is always possible to modify the plan during the operation.

The research proceeded step by step, with experimental confirmation in each phase. The first tasks were devoted to build the experimental system and to establish an adequate motion control of the ASVs. Then, formation control aspects were tackled. After that, the research focused on boom towing, with many different experiments. As expected, during the research a number of control issues appeared, mainly related to keep the formation along the planned operation. It is not the same problem as keeping a parallel formation of free ships, because of the towing effort and the physical link between ships through the boom.

The order of the article essentially reflects the sequence of steps just described. After considering the background pertinent for this research, the article introduces the experimental system, with the ASVs and the ground station, and then pays attention to the motion control of the ASVs at individual level. The article continues with a section that considers how to get a parallel formation of free (not

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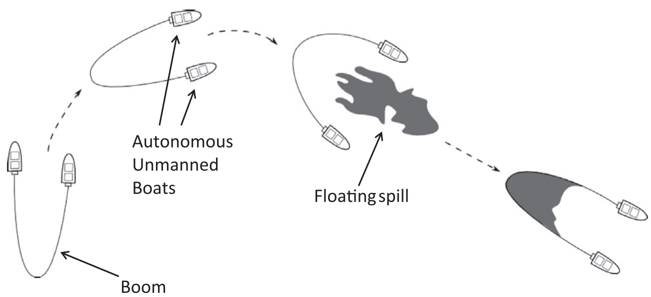

Fig. 1. An sketch of the proposed automatic spill recovery operation using two ASVs.

mutually linked) ships. Next, a subsequent section focuses on the most peculiar aspects of the article: the dynamic phenomena involved in towing, and how to maintain the parallel formation while towing. Once these aspects were under control, it was possible to design and execute fully automated operations; this is described in the sixth section. Finally, the last, short section draws some conclusions and comments immediate future work. As it will be seen along the article, the experimental results already obtained are quite encouraging.

2. Background

In their article on oil spill response planning, Zhong and You (2011) give the following details of what happened with the Deepwater Horizon disaster in the gulf of Mexico: 210 million gallons of crude oil was released affecting 180,000 km^2 of ocean surface, 39,000 personnel, 5000 vessels and 110 aircraft were involved in cleaning, over 700 km of booms were deployed.

Our research focuses on boom towing for spill recovery. A lot of information about marine spills and remediation can be accessed from 'The International Tankers Owners Pollution Federation Limited (ITOPF)' web site; in particular, the use of booms in oil pollution response is well described in one of the documents of that site, ITOPF (2014). The following special interest information items can be extracted from this document. Most conventional booms designs are not capable of containing oil against water velocities much in excess of 1 knot (0.5 ms^{-1}). There are several types of booms, from inflatable low-cost, to complex structures combining curtains, chains, and other parts. The approximate force on a 100 m length of boom with a 0.6 m skirt in a 0.5 knot current would be 375 kg. Booms should not be attached directly to towing vessels, instead towing lines of sufficient length should be used between boom ends and the ships; a typical case would be lines of 50 m for towing a 300 m boom. Vessels should be able to maintain the correct configuration of the towed boom at very low speeds.

Another source of professional information on spill recovery is the 'International Oil Spill Conference (IOSC)' repository, accessible from the web. A detailed parameter study of a boom is presented in Chung et al. (1973), including an empirical formula for determining tow-line tensions and a series of design recommendations, like that the boom length should be much smaller or much larger than the average wavelength (the study pays attention to the effect of waves on the boom dynamics). In their short contribution (Allers and Penny, 1995), it is sustained that the role of a recovery system is first to contain spilled oil and then to concentrate the oil such that skimmers may operate with efficiency; a V-shape boom geometry was recommended. A containment-recovery system is described in Glaeser (1973), with photographs and sketches; the system includes two tow-boats, the boom, and a tug between these boats towing a barge for skimming. In Nordvik et al. (1995), a full scale testing at sea is presented, with three ships towing a double-U boom; four different booms were tested, with lengths of 106.7 m, 400 m, 200 m, and a combination of several booms; it was found that the measured loads were clearly higher than those predicted by theory.

An interesting part of the information provided by IOSC, concerns reality: what can be used, how to mount an organization, what to do in case of an emergency. Two papers in particular, Hall et al. (2011) and Parson and Majors (2011) give the principal details of how a nearshore Vessel of Opportunity skimming capability was organized as part of the response to the Gulf of Mexico disaster. One of the main tactics that were decided, as represented in the photographs and drawings of these papers, is similar to the recovery operation we are considering in this article. Fishing vessels were chosen, and this was natural since fishers are familiar with cooperative tasks involved in towing a net, and the ships were designed for such tasks. By the way, a simplified model for bottom trawl fishing gears can be found in Folch et al. (2007), including balancing of forces and balancing of moments. Numerical modeling of boom and oil spill is presented in Zhu and Strunin (2002) and Violeau et al. (2007).

In the scenario proposed in this article there are several aspects of interest for the robotics and control community, since it is based on a parallel formation of two ASVs following a pertinent path. The terminology is not completely fixed in the literature, papers refer to ASVs (autonomous surface vehicles), AMVs (autonomous marine vehicles), USVs, etc. A general, important reference for dynamics and motion modeling of marine vehicles is Fossen (2002). The kind of issues that have to be solved for trajectory planning and tracking by ASVs is well reflected in Liao et al. (2014), with opportune discussion of references. The case of path tracking by a formation of ASVs is treated in Liangsheng and Weisheng (2011), which identifies three general methods of formation control (leader-follower, virtual structure, and behavior method) and another three methods for path tracking; it is said that follow-the-leader is usually preferred in the marine context. The interesting paper of Breivik and Hovstein (2008) on ASV formation control, contains also a relevant list of references.

When one observes a formation of birds, it is clear that no communication is needed, only local sensing; this is the main point in the proposal of Peng et al. (2010, 2013), for ASV formation control in the presence of uncertainties. Another aspect is collision avoidance, which is obviously important for ships; the thesis of Vintervold (2010) deals extensively with this issue within the scope of marine survey operations. Some international research projects have been launched in relation with homogeneous or heterogeneous teams of autonomous vehicles; this is the case of the GREX project, described in Aguiar et al. (2009) with numerous references. One of the diagrams in this paper shows four layers to be considered: vehicle dynamics, navigation and control, cooperation strategy, and logic-based communication. An application of GREX is marine habitat mapping.

In our scenario, there is a physical interaction of both ASVs, since they tow a boom together. Some similarities with this can be found in Arrichiello et al. (2010, 2012), where two ASVs tow a floating rope for a caging operation. Many papers on fleets of marine robots show only simulations; while a few show experimental results, like in the case of Arrichiello, et al. (2010, 2012), using two 2.1 m long ASVs on a lake. The paper of Bhattacharya et al. (2011) is also related with this experimental scenario, and includes an interesting study of rope dynamics.

There are some recent papers that offer some new alternatives for oil spill response. In Jin and Ray (2014) a swarm of ASVs, each one with cleaning capabilities, have to explore an area to find targets. In Zahugi et al. (2012) a swarm of ASVs have to surround and contain an oil spill.

Regarding to our experience, a first autonomous scaled ship was developed and tested in Recas et al. (2004), a first consideration of