SIMULATING AN AUTONOMOUS SHIP FOR SEA DEMINING

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Abstract

The paper deals with a sea demining system using autonomous marine surface vehicles (AMSV). The research involves the development of exemplars of these vehicles, and the procedures for area scanning and coverage. The demining is made by field influence, towing a submerged "fish". This study is made both with simulations and with scale experiments. The paper focuses on modeling, based on first principles and experiments, and then in simulation. For modeling a scaled AMSV has been built, and it is currently used to get modeling data and for simulation verification.The simulation is oriented towards path planning and path following for better area coverage in order to clean an area. The simulation uses a realistic map background, for mission planning in the actual constraints.

Keywords: Modeling and simulation of autonomous ship, sea demining, autonomous surface marine vehicles, unmanned surface vehicles (USV), robot area coverage

Presenting Author's biography

Jose Maria Giron-Sierra was born in Valladolid, Spain. He received the Licentiate (1972) and the Ph.D. (1978) degrees in Physics from the Universidad Complutense de Madrid, Spain. He is Full Professor with the Department of Computer Architecture and Automatic Control of the Universidad Complutense de Madrid, Spain, from 1988. He has been the author of 180 publications in conference proceedings and journals. His research is related to applied automatic control and simulation: ships, airplanes and spacecrafts, robotics, process control. His research interests are autonomous ships, simulation, real-time remote monitoring and control, optimisation based on genetic algorithms. Dr. Giron-Sierra is a Member of the IFAC Technical Committee on Marine Systems.

1 General

There are sea regions in the planet with drifting or buried mines, some of them from the Second World War. For example, it is estimated that some 80,000 or 100,000 mines are still in the Baltic Sea area. This means a serious danger calling for remedies. It is clearly convenient to use robots for demining, with no risks for humans.

Among the methods for elimination of sea mines, there is one suitable for buried old mines, which is *influence demining*. The demining system generates a powerful magnetic and electric field, to cause mine detonation. In general, no previous knowledge of exact mine positions is available, so the idea is to pass several times the electric and magnetic fields on a suspected region, trying to cover all the intended area.

Fig.1 Sea mine detonation.

The target in our research is to develop an autonomous marine surface vehicle (AMSV) for influence demining, and the procedures to use it in automated manner.

The basic idea is that the AMSV tows a submerged "fish". Both the towing cable and the fish are used to radiate electric and magnetic fields. The fish has adjustable flaps, in order to keep it some 3m under the sea surface.

Notice in figure 1 the size of the mine detonation compared to a ship. It is desired that mine detonations do not destroy the AMSV. Therefore the length of the towing cable is relatively large, of the order of 200m for a 4m. AMSV.

The scanning of an area with the towing system constitutes a peculiar problem, which requires experiments, mathematical models and simulations. In order to validate models, our research has started with the development of scaled AMSV, so experiments can be done in ponds near our laboratory of robotics.

Suppose you tow a small plastic buoy on the sea. You try to follow a scanning procedure by corridors and turnings [1]:

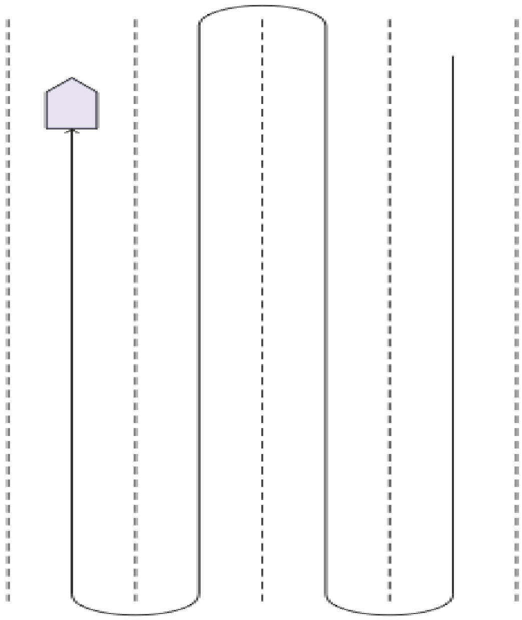

Fig.2 Corridors and turnings

If you are navigating along a straight corridor, the main problem for the AMSV is to counteract course perturbations due to wind and currents. When the AMSV has to turn, some important problems could appear: if the cable looses tension, you risk colliding with the fish, or being near the fish just when a mine explodes. It is important to develop a model in order to study control and trajectory issues pertaining turning [2]. Moreover, since the AMSV is on the sea surface, it suffers the influence of current, waves and wind, whilst the fish only suffers the influence of current: the motion of the fish could be different from the AMSV motion, and it may happen that a certain area you believe has been covered, has been forgiven. Again, it is important to simulate the system behavior.

The paper starts with a section on modeling, and another section on simulation aspects. The third section is more oriented to simulation use with reference to geographical contexts. The last section is devoted to experiments. The paper ends with some conclusions and a prospective view of future work.

2 Model of the system dynamics

At this stage of the research a somewhat simplistic model has been developed. The model should be refined after several experiments. The model is based on 3 DOF (Degrees Of Freedom) equations of motion of the ship and the attached fish. Future more complicated models could be based on [3, 4, 5].

Figure 3 shows a sketch of the model geometry.

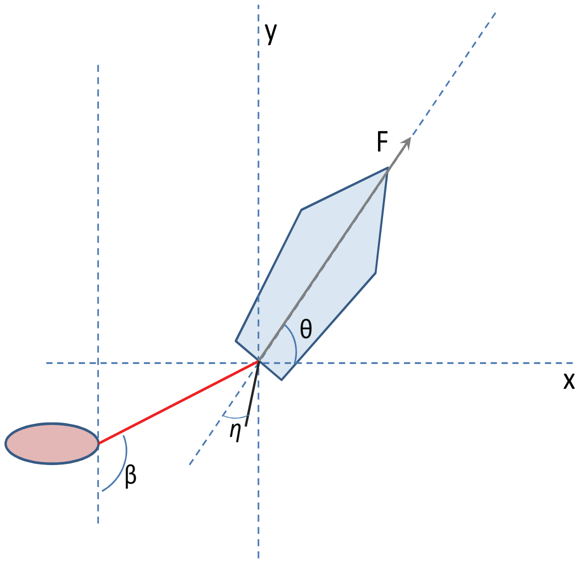

Fig. 3 Sketch of the model geometry

The blue box represents the AMSV and the red ellipse represents the trailer (the "fish") that is being towed. *F* is the thrust force given by the boat's engine, η is the helm angle and θ is the boat's heading angle.

The AMSV is governed by the following equations:

$$\dot{u} = (F \cdot \cos\eta \cdot \cos\theta - \mu_t \cdot u) \cdot \frac{1}{m}$$

$$\dot{v} = (F \cdot \cos\eta \cdot \sin\theta - \mu_t \cdot v) \cdot \frac{1}{m} \qquad (1)$$

$$\dot{\omega} = (F \cdot d_{cm} \cdot \sin\eta \cdot \sin\theta - \mu_r \cdot \omega) \cdot \frac{1}{I}$$

Where there are two linear motions, according with the axes in figure 2, and a rotational motion of the ship.

When the ship moves, a "wall" of water develops at the bow, and more water around the ship moves with the ship. That means what in the marine modeling field is called ´added mass'. In general, the mass and the inertia included in the equations increase when speed increases. Likewise, friction coefficients change when speed changes. Therefore, the equations may look linear, but coefficients depend on speed. Given a constant regime speed, one can consider constant coefficients, and the model agrees easily with experimental data. The nonlinearities manifest only during speed transients.

Figure 4 shows the agreement of the model to experimental data. The speed of the ship has been measured along a straight path, during 80 seconds. The agreement is good for constant regime, and it diverges, not much, for start and stop transients.

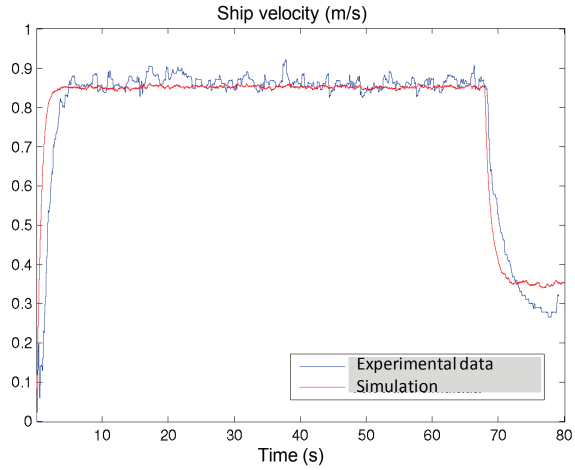

Fig. 4 Model and experiment agreement

Next table shows the values of model coefficients. These values correspond to the scaled ship we are using for experiments.

Tab. 1 Model coefficients

μ_t	$3Kg \cdot s^{-1}$
μ_r	$2Kg \cdot m^2 \cdot s^{-1}$
m	$3Kg$
d_{cm}	$0.5m$

The real AMSV will be considerably bigger than the scaled ship. A reason for the use of a simple mathematical model is that it can be adapted easily to the characteristics of the real AMSV, in terms of coefficient changes. And the new coefficients can be experimentally determined with the same procedures we followed with the scaled ship.

The trailer movement is a bit different. There are two different possibilities depending on the distance between the trailer at time *t-1* and the boat at time *t*.

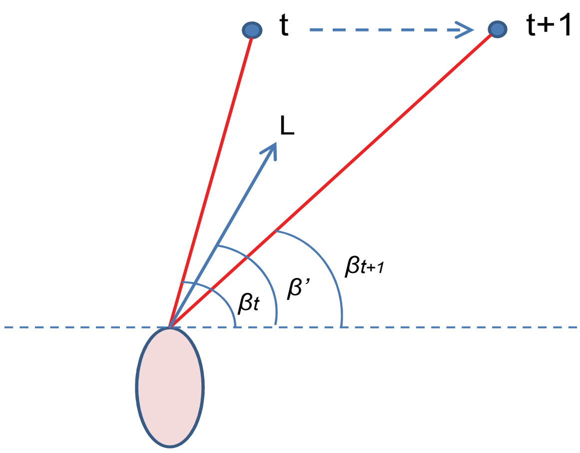

Fig. 5 Trailer movement

If the distance between the trailer at time *t-1* and the boat at time *t* is less than the length of the string, the trailer doesn't suffer any acceleration. It moves due to its inertia and is decelerated according to its linear drag coefficient.

Otherwise, the trailer moves along direction *L* (see figure 5). The displacement along *L* is such that the distance between the trailer and the boat is the length of the string. For the moment we do not consider cable dynamics, so there are no catenary arcs, nor elastic cable forces. In a further step, we plan to conduct real scale experiments to get data and be able to include this in the mathematical model.

The tension on the string at time *t* can be calculated as follows:

$$\begin{aligned} \overline{v}_t &= \frac{\overline{p}_t - \overline{p}_{t-1}}{dt} \\ \overline{a}_t &= \frac{\overline{v}_t - \overline{v}_{t-1}}{dt} \\ \overline{T}_t &= m \cdot \overline{a}_t \end{aligned} \tag{2}$$

Where velocities are computed according with ship position changes, and then acceleration is computed, and then one obtains the cable tension.

3 Simulation of the demining system

Using the model, a first simulation tool has been developed for AMSV control studies. Our idea is to use at the beginning conventional PID control for heading and speed. In a further step we plan to use fuzzy control. The model includes the dynamics of the AMSV, so responses to control can be observed in terms of AMSV trajectories.

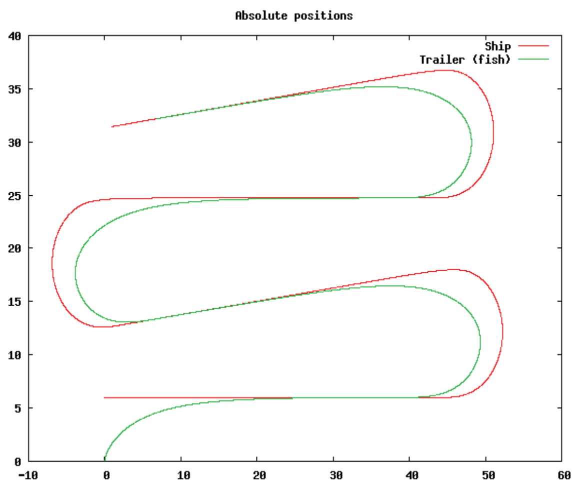

Fig.6 Simple corridors and turnings simulation.

A simple trajectory for sea demining using corridors and turnings can be simulated as seen in figure 6.

Notice in figure 6 how the fish trajectory differs from the AMSV trajectory, especially when turning.

Since the real AMSV in the conceptual design phase, it is important to evaluate, using the simulation, what difficulties could appear when towing the fish. For instance, what type of forces should be sustained by the cable, and the ship.

Next figure shows the predicted tension on the towing cable for the simple case considered in figure 6. There are important peaks.

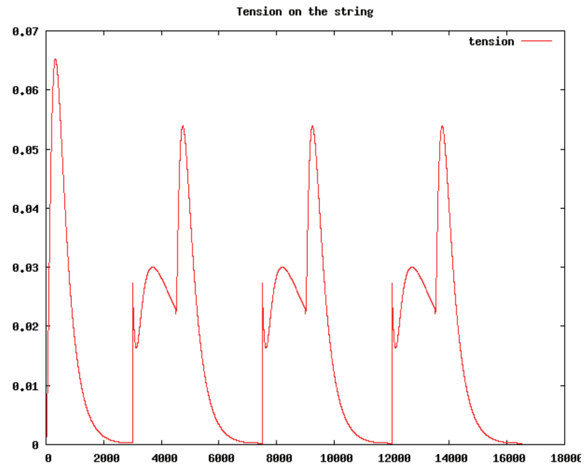

Fig.7 Tension on the string.

A possible mechanical solution to alleviate effects on the ship stern is to include some type of elastic join to the cable.

4 Trajectories for sea demining

If no a priori information on mines locations is available, a systematic scanning is in order.

Given a particular sea-demining scenario, the area coverage in terms of corridors and turnings must be specified by a human manager. We are developing tools for helping at this demining operation stage. Part of these tools is a simulation with geographical support. Of course this simulation is based on the mathematical model, and the simulation versions made for control design work.

Next figure shows a simulation using real coordinates (Cartagena harbor, Spain). This provides the ability to plan and test missions on real places. A Keyhole Markup Language (KML) file is generated by the simulation tool. This file can be loaded in geographic tools such as Google Earth for inspection.

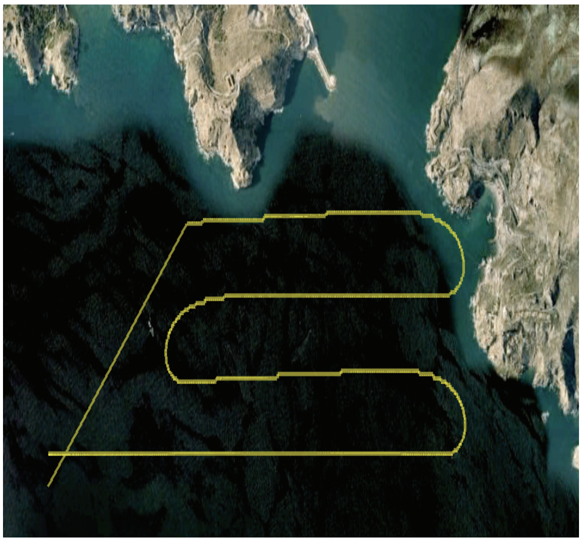

Fig.8 Geographical simulation support.

The idea with the operational simulation environment is to facilitate the human interface. The user simply put on the screen corners of the area to be explored in the geographical scenario. Then the simulation generates corridors and turns for good area coverage, and then it shows the predicted effect of the fish towing operation, in terms of area bands being influenced by the electric and magnetic field over a certain specified intensity threshold.

The AMSV is informed about the trajectories to accomplish by a script [6] [7]. This script is simple. Every part of the script consists of a series of open-loop orders and a checkpoint. These orders are to be meant to interact with both actuators on the ship. The software will advance through the different parts as it reaches the different checkpoints. Currently, the orders are:

- *set-ship-delta* – sets the ship heading. This is only useful in an initial configuration part.
- *set-ship-force* – sets the amount of force as a fraction of the maximum force.
- *set-ship-helm* – sets the helm to the desired position.

For now, the only checkpoint supported is a time value. The orders will be valid during the time specified in seconds.

New orders related to specification of geographical waypoints are now under development, with experimental verifications.

The operational simulation environment includes a series of menus for specification of wind, current and sea state.

5 Experiments

From the beginning, the development of the model and simulations has been supported by experiments.

Two scaled AMSV have been developed, as 1m. long zodiacs with outboard electric propeller. The zodiac speed and heading can be controlled using standard RC servomotors.

A complete electronic on-board control system has been developed for autonomous control. This system includes GPS, compass and Pitot tubes. With these sensors the ship knows heading angle, speed and position. It has a memory card, the same as in photo cameras, for data recording. Scripts can be loaded to the ship via digital radio from a external computer.

Figure 9 shows a photograph of one of the experiments, in a public pond (sometimes surrounded by pets, and putting ducks in closer contact with science). In this case, the towed fish has been represented by a red buoy. With some effort, the towing string can also be seen in the photograph.

Fig.9 Simulation verification experiments.

First experiments were driven towards model establishment. Towing forces were measured with electronic gauges at different propeller powers. The same series of powers were applied in straight trajectories, and velocities were measured. Figure 10 shows a simple linear fitting of the damping coefficient for translational motion.

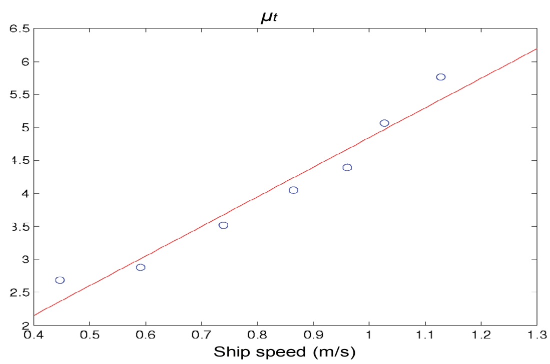

Fig.10 Fitting of the damping coefficient

Next, several experiments considered alternatives for ship speed control. Once a good PI control was established, another series experiments focused on heading control. This was combined with a first version of scripts. A square was commanded to the ship, and was effectuated using speed and heading control.

Figure 11 shows experimental data of the heading angle in the square following experiment.

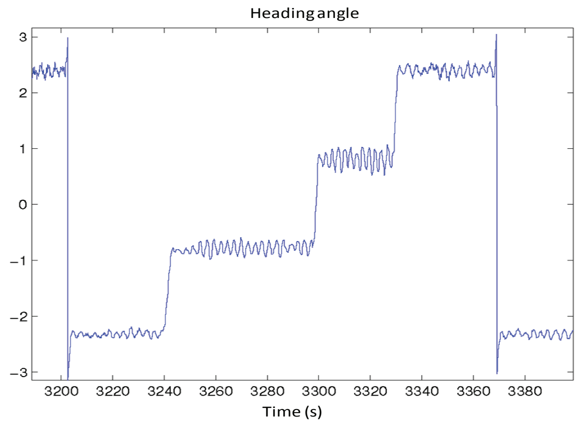

Fig.11 Heading angle along a square

Figure 12 shows the trajectory of the ship, as recorded on-board with the GPS.

Fig.12 First experiment with a square trajectory

A further step in the experiments has been to be able to insert waypoints, and make the ship go from one to another waypoint. Then, we put a GPS on the fish, and recorded the motion of the AMSV and the towed fish in a first example of system motion.

Figure 13 shows first experimental results with a series of waypoints, forming an 8. The fish position is represented in red color. Trajectories correspond fairly well to it was predicted. The system repeated three times the same cycle, to see the repeatability of the motions.

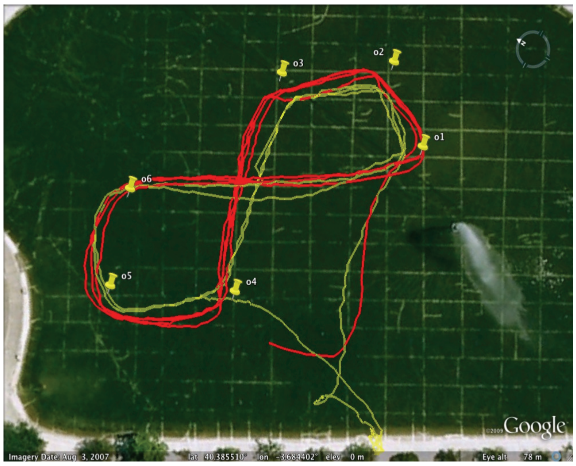

Fig.13 Experiment with waypoints and towed fish

6 Conclusion

This is a work in progress report. Now, summer, we are starting experiments with a large new AMSV. The simulation environment is gaining functionality, following users indications.

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