The EU-MOP Concept: A Swarm Robotics Approach for Oil Spill Control

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Abstract
This paper introduces an ongoing EU research project called EU-MOP, which involves the design and evaluation of an intelligent and efficient robot system to respond to oil spills. The EU-MOP project addresses both unit and system level (i.e. unit design and emergency response topics) so as to draft a complete proposal/solution regarding oil spillage. The paper defines the objectives of the project, presents the underlying concept and discusses some of its up-to-date results.

1. Introduction

The purpose of this paper is to present the concept of an intelligent swarm system to respond to oil spills, in the outline of the EU-MOP project. EU-MOP stands for “Elimination Units for Marine Oil Pollution” and is a research project co-funded by the European Commission, Directorate General for Research and Technological Development, in the context of the 6th Framework Programme. The project started in February of 2005 and has a duration of 3 years. The EU-MOP consortium is coordinated by the National Technical University of Athens (Greece), and also includes as partners the University of Glasgow and Strathclyde (UK), Sirehna S.A. (France), Instituto de Soldadura e Qualidade (Portugal), BMT Ltd (UK), Cetemar S.L. (Spain), Environmental Protection Engineering S.A. (Greece), Aurensis S.L. (Spain), the University of Oxford (UK), Consultrans S.A. (Spain), Bureau Mauric S.A. (France), the Institute of Shipping Economics and Logistics (Germany) and IPA Fraunhofer (Germany).

Although this project is ongoing, in this paper the underlying concept and selected preliminary results are presented accordingly. To that effect, the rest of this paper is structured as follows. Section 2 provides some background on the problem. Section 3 describes the objectives of the EU-MOP project. Section 4 discusses oil spill scenarios and statistics and Section 5 talks about operational specifications, design issues and AI. Finally Section 6 outlines future plans.

2. Background

Oil pollution, arising either from marine accidents or from routine ship operations, is one of the major problems that threaten the equilibrium of the marine environment. Only estimates can be given on the quantity of oil that
finally ends into the sea, from all possible sources (maritime transport, fixed-shore installations etc). Table 1 gives an overview of oil spills in Europe from 1990 to 2004 (Vergetis et al, 2005).

Table 1: Distribution of European spills (medium and large ones) for the time period 1990-2004.

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Spills</th>
<th>Total Number of Spills</th>
<th>Total Spilled Quantity &gt;7 tons (in tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7-700 tons</td>
<td>&gt;700 tons</td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td>14</td>
<td>5</td>
<td>19</td>
</tr>
<tr>
<td>1991</td>
<td>7</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>1992</td>
<td>11</td>
<td>3</td>
<td>14</td>
</tr>
<tr>
<td>1993</td>
<td>10</td>
<td>3</td>
<td>13</td>
</tr>
<tr>
<td>1994</td>
<td>9</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>1995</td>
<td>5</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>1996</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>1997</td>
<td>5</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>1998</td>
<td>5</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>1999</td>
<td>5</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>2000</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>2001</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>2002</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2003</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>2004</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

The efforts in protecting the environment after an oil spill (through an anti-spill operation) could cost in billions of euros in cleanup and damage costs and often produce questionable results. The most expensive oil spill in history was the one caused by Exxon Valdez (Alaska, 1989). Cleanup alone cost about US$2.5 billion and total costs (including fines, penalties, claims settlements, etc) are estimated at US$9.5 billion. The Amoco Cadiz spill in France (1978) reportedly cost about US $282 million, of which about half was for legal fees and accrued interest. Claims are still being processed for the Erika spill in France (1999), and are likely to considerably exceed the US$ 180 million which is available under the 1992 Civil Liability (CLC) and Fund Conventions. It is obviously early to accurately estimate the total cost of the Prestige oil spill, but it is again likely that it will reach up to hundreds of millions of euros.

The issues of oil marine pollution and oil spill confrontation have attracted increasing research attention over the past 25-30 years. The preservation of the marine environment is of extreme importance and therefore all possible dangers that threaten must be dealt with determination and efficiency. In this context, the MIT Oil Spill Project has contributed significantly in the areas of strategic and tactical planning, that is, through the optimization of an effective anti-pollution network and of tactical and strategic response management (Psaraftis and Ziogas, 1985, Psaraftis et al, 1986). Moreover, the integration of oil spillage problem with safety techniques (e.g. fault trees, event trees, risk contribution trees, HAZOP etc) presents the necessary potential to compose
an efficient operational framework, in terms of danger awareness, spill prevention and adequate pollution confrontation (Ventikos, 2002).

The International Convention on Oil Pollution Preparedness, Response and Cooperation provided a framework for international cooperation for combating major oil pollution incidents and places various obligations on signatories. The mandatory requirements of the Convention include Articles on Oil Pollution Emergency Plans, National and Regional Systems for Preparedness and Response, and International Cooperation in Pollution Response. Also, the European Maritime Safety Agency is very active in this area, and has developed an appropriate Action Plan (EMSA, 2004).

The key factor for efficient clean-up operations is to develop an adequate structure focusing on the confrontation of oil when this is floating into the sea. This means that a well-planned operation should try to confront the oil when this is still into the sea and diminish its possibilities to impact the nearby coasts.

3. Objectives of the EU-MOP project

All the above converge to the fact that there is an existing and direct need for a continuous renovation of the relative anti-pollution methodologies and equipment, always striving for the minimization or even elimination of the adverse effects an oil spill has on the environment. Such a goal must be incorporated in all hierarchical levels, taking at the same time all necessary legislative and surveillance measures to prevent the emergence of oil spills in the first place. However, it is an undisputed fact (and something that maritime history repeats explicitly), that as long as oil-carrying vessels sail the seas, tons of oil will eventually end up in the seawater. In effect, and taking into account the increase of oil-related traffic of recent years efficient operational, in situ, techniques that allow for the control and the elimination of observed oil spills, are imperative.

The specific objectives of the EU-MOP concept are to:
1. Develop innovative intelligent robot technologies for oil spill management;
2. Design and set the basic principles of these autonomous units for oil spill confrontation;
3. Formulate an integrated structure for oil spill management and logistics at both the strategic and tactical levels;
4. Introduce an advanced structure (dissemination) concerning oil pollution response policy.

There are a number of elements concerning this research that make it particularly appealing for the maritime industry and for the preservation of the marine environment:
- The research is multidisciplinary and encompasses areas of particular technological innovation. Below are some of the technological challenges involved and possible routes that the research could propose to face them are briefly outlined:
  - Energy source and propulsion;
Intelligent, cost-effective, and manageable technique to combat oil spills. They carry no side effects, no dangerous materials on-board and no possibility of harmful action. They would significantly save on the labour costs of cleanup;

- Oil pollution emergency (crisis) management. The project formulates an advanced approach for spill management issues for both the strategic and the tactical level of response. Thus it presents an integrated solution concerning the overall framework for the mobilization and application of anti-pollution means;

- Industrial appeal. The envisioned units will be designed and assessed (proof of concept), assembled from inexpensive materials. This surely makes them, in the long run, an appealing challenge for the industry, since they will be efficient, patentable, and will allow for an adequate profit margin.

In the sections that follow a very limited yet indicative sample of the results of the EU-MOP project is given, by focusing only on a few of them.

4. Oil Spill Scenarios and Statistics

In Mamaloukas-Frangoulis (2005) the marine oil spill scenarios that are incorporated in the EU-MOP project are addressed accordingly. The common characteristics of different oil spills and their respective response operations are grouped into a limited number of scenarios involving the use of EU-MOP units. Scenarios selected have been drafted in order to define the spectrum of operational demands (portfolio) for the EU-MOP units.

The report in Vergetis et al (2005) draws from a multidimensional list of potential oil spill data sources, such as maritime Authorities, international organizations, EU-MOP partners, and others, highlights and furthermore elaborates on significant pollution related statistical data in order to develop a state-of-the-art baseline regarding operational and strategic aspects of pollution confrontation and control. It is noted that other similar approaches such as the ones originated from ITOPF, Clarksons, EMSA, and others, have been identified, but to the knowledge of the authors of this paper none of them achieves the depth of detail or the specific application of risk driven methodologies as it is the case with the above report. Several sources of information have been tapped, including (but not limited to) ITOPF, EMSA, REMPEC, HELCOM, the Bonn Agreement, SASEMAR, ACOPS/MCA on oil spill data, the EU ‘Eurowaves’ project on wave and other environmental data, and a variety of sources on maritime traffic data. As a result of this analysis, ten (10) priority areas in European waters have been identified and presented under the umbrella of the geographical position of each broader region. Figure 1 depicts these risk areas, superimposed on a map also showing previous oil spill events.
spill locations, as well as the main oil traffic lanes, ports and refineries in Europe (Vergetis et al, 2005).

Figure 1: Geographical distribution of European oil spill risk areas.

Specifically, the risk areas are broken down as follows:

**Mediterranean Sea:**
- Risk Area 1: The Aegean Sea;
- Risk Area 2: The Southern Region of Sicily (Straits of Sicily);
- Risk Area 3: The North Adriatic Sea;
- Risk Area 4: The Straits of Gibraltar.

**Atlantic Front (European Atlantic):**
- Risk Area 5: The Galician Coast NW of Spain;
- Risk Area 6: The English Channel (e.g. its approaches).

**North Sea:**
- Risk Area 7: Off the Coasts of the Netherlands and Belgium;
- Risk Area 8: The UKCS and the Area of NE of the UK.

**Baltic Sea:**
- Risk Area 9: The Kiel Canal & the Entrance to the Baltic Sea;
- Risk Area 10: The Entrance to Gulf of Finland.

Sea state and other weather variables are also very important when examined in conjunction with various aspects of ship source oil pollution. For instance, bad weather conditions are a significant causal factor for many marine accidents; many of them leading to oil spills. The break-up of the tanker ‘Prestige’ was accelerated by bad weather. Also, the rate at which the oil spreads is strongly determined by the prevailing conditions such as local temperature, water currents, tidal streams and wind speeds. The more severe the conditions are, the more rapid the spreading and breaking up of the oil is.
Last but not least, clean-up operations and their success are strongly dependent upon weather conditions, especially in the open sea. Two key questions are: (a) is there a connection between the recorded oil spill incidents and the prevailing weather conditions? And (b) where and under which environmental conditions (wave height, wind speed, direction, currents, etc) is the EU-MOP concept capable of operating?

With respect to the first question, and even though as noted above bad weather conditions certainly increase the risk of an accident that can lead to oil spillage, none of the oil spill data sources in disposal of the authors of this paper had an explicit connection to and adequate explanation of the weather conditions prevailing at the time of the spill. If anything, there was only an oblique (and certainly not fully explained) connection between spill volume and time of the year that the spill occurred, with large spills not likely to occur in the July-September quarter.

With respect to the second question, it is obvious that the sea state and other weather and environmental variables are important for at least the operational specifications and the design criteria of the EU-MOP units. To that effect, a comprehensive statistical analysis of such variables was performed for European waters (Vergetis et al, 2005); as an example, Table 2 provides the frequencies of significant wave heights ($H_s$) for the Mediterranean Sea.

### Table 2: Cumulative frequencies of significant wave height, $H_s$ (Sea and Swell) for the Mediterranean Sea.

<table>
<thead>
<tr>
<th>Month</th>
<th>Wave Height &lt;1m</th>
<th>Wave Height &lt;2m</th>
<th>Wave Height &lt;3m</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>52.34</td>
<td>81.73</td>
<td>92.91</td>
</tr>
<tr>
<td>February</td>
<td>53.97</td>
<td>82.03</td>
<td>93.40</td>
</tr>
<tr>
<td>March</td>
<td>56.25</td>
<td>85.00</td>
<td>94.80</td>
</tr>
<tr>
<td>April</td>
<td>59.20</td>
<td>87.86</td>
<td>96.72</td>
</tr>
<tr>
<td>May</td>
<td>73.44</td>
<td>94.76</td>
<td>98.91</td>
</tr>
<tr>
<td>June</td>
<td>73.66</td>
<td>95.10</td>
<td>99.06</td>
</tr>
<tr>
<td>July</td>
<td>73.75</td>
<td>95.69</td>
<td>99.36</td>
</tr>
<tr>
<td>August</td>
<td>79.24</td>
<td>96.90</td>
<td>99.58</td>
</tr>
<tr>
<td>September</td>
<td>71.31</td>
<td>94.17</td>
<td>98.99</td>
</tr>
<tr>
<td>October</td>
<td>68.50</td>
<td>92.00</td>
<td>97.80</td>
</tr>
<tr>
<td>November</td>
<td>53.80</td>
<td>83.42</td>
<td>94.07</td>
</tr>
<tr>
<td>December</td>
<td>48.50</td>
<td>79.27</td>
<td>91.97</td>
</tr>
</tbody>
</table>

5. Design, AI and Operational Characteristics

In Mamaloukas-Frangoulis et al (2005), an EU-wide current inventory regarding marine oil pollution response units and equipment is reviewed, along with a description of the advantages and disadvantages of each type of antipollution equipment in order to point out deficiencies of the existing antipollution systems during clean-up operations; hence draft the “competition” for a future application of the EU-MOP solution.
In Ventikos et al (2005), the necessary operational specifications regarding the adequate development and usage of the EU-MOP proposal are presented. The report covers specifically important components such as artificial intelligence and robotics, and the oil processing properties and capabilities of the proposed units.

In Lemesle et al (2005) alternative Catamaran and “Monocat” concepts are adequately analysed with criteria based on volume, weight, skimming device integration potential, load carrying potential, speed performance, and stability, bearing in mind the given technical requirements. Figure 2 gives a preliminary view of the proposed monocat version for the large (L) model of EU-MOP units.

![Figure 2: Monocat design for the large (L) model of EU-MOP units.](image)

The overall artificial intelligence structure for the EU-MOP system is developed in Fritsch et al (2005). Hence, the derived structure shows the basic components of the discussed solution along with the interactions of them in an internal level and with the external framework (e.g. surrounding environment). In effect, the selected structures will lead to several facts and consequences:

- The EU-MOP units will be able to receive commands and information directly from the master control station (MCS) and indirectly from the tactical decision maker;
- This architecture incorporates several levels of intelligence of the master control station:
  - Translator;
  - Translator and shared memory;
  - Translator, shared memory and information processor;
  - Translator, shared memory, information processor and shared decision maker;
- The tactical decision maker is the responsible person for the EU-MOP system.
In Fritch et al (2006) numerous swarm strategies for the control of the individual units/robots are developed accordingly. Swarm strategies are simple rules which enable a flexible, robust and self-organizing swarm to efficiently cope with its tasks. In the EU-MOP context, these strategies will be linked with different identified scenarios, e.g. swarm strategies for the elimination of oil pollution at the open sea under bad weather conditions, or for the elimination of pollutions in harbors. Communication plays a major role in multi robot systems. It enables the system to increase its performance tremendously (Figure 3)

In Chatzinikolaou et al (2006) the main objective is to identify the key requirements for the selection of the oil handling means onboard the EU-MOP units. This selection procedure concludes through a methodology developed to measure various skimmer configurations performance, in relation to the implemented requirements from a qualitative perspective. Hence the criteria for the selection procedure can be summarised as below:

- Type of confronting oil;
- Operational limits due to the prevailing weather/environmental conditions;
- Size and weight;
- Power requirement of the skimming device;
- Oil/water ratio in the collected quantities;
- Debris handling capability;
- Oil Recovery Rate (ORR);
- Recovery Efficiency (RE);
- Need for auxiliary equipment.

Currently, significant amount of analysis is being performed focusing on the design of all size models for both EU-MOP unit hull shapes; namely the monocat and the catamaran modules. This can be translated into weight distribution, hydrostatic and hydrodynamic assessment, seakeeping calculations, design of preliminary general arrangements for the units etc, so
as to come up with the best possible (and realistic) solution for all scenarios identified in the EU-MOP operational portfolio. Indicatively, Figure 4 depicts a sample of the hull and main characteristics of the EU-MOP Large (L) model for the catamaran design and Figure 5 gives a preliminary 3-D overview of the arrangements on board the aforementioned EU-MOP model.

**Figure 4:** Sample of main characteristics for the large EU-MOP catamaran.

**Figure 5:** A preliminary overview of the large EU-MOP catamaran.
Figure 6 shows the wave field for the large EU-MOP catamaran at a transit speed of 5 knots; elaboration and optimization of these results will be performed during the second loop of design for the EU-MOP units.

**Figure 6:** Wave field at 5 knots for the L catamaran EU-MOP unit.

### 6. Plans ahead

Work ahead includes further development on the design of the unit (for both catamaran and monocat versions and for all three models, L, M and S), on the artificial intelligence approach (mainly on the operational/simulation side), on the oil processing scheme, on cost-benefit analysis and on response logistics at the strategic and tactical levels. With respect to the last issue, the project is formulating an advanced approach for spill management issues, including mobilization, application tactics, strategic management, logistics, etc. Emphasis will also be given on the logistics and support chain of the EU-MOP concept and operation: the implemented logistics and the corresponding techniques are properly assessed in terms of efficiency, functional facilitation and continuous service enhancement. This way, the emergency response management component will acquire a realistic structure and consequently be able to provide the best possible protection of the marine and coastal environment. Progress on all these issues will be reported in future publications.

### 7. Acknowledgments

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### 8. References


