Towards the Use of a Team of USVs for Civilian Harbour Protection: the Problem of Intercepting Detected Menaces

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***Abstract*— Protecting civilian harbours is a field which has received increasing interest after the attack of September 11th. Exploiting a team of Unmanned Surface Vehicles (USVs) for the protection of harbours is one of the areas under major investigation. Indeed the USVs could be used to perform patrolling around the crucial waterways or to investigate possible suspect vessels, increasing the effectiveness of the security system, while at the same time decreasing the number of human beings directly exposed to threats. The coordination of such a team of USVs is the goal of an on-going joint research project, the Swarm Management Unit (SMU), between the authors' organization. This work presents the latest results of the SMU project, i.e. a menace interception system composed by the on-line selection of the best interceptor coupled with the off-line optimization of the positioning of the team of USVs.**

I. INTRODUCTION

Since the terroristic attack of September 11th, the security of civilian transportation systems and stations has received increasing interest. Among those, civilian harbours are peculiar since they are exposed to attacks coming from the so-called "blue border" (i.e. the sea-side), which is harder to keep under tight control. For this reason, the need for innovative and reliable technologies, improving the current harbour security infrastructures, has been expressed by different governments and international institutions. Among them we can cite as example the NATO's Defence against Terrorism programme [1], which has listed the harbour protection problem as one of the ten main areas of work, where new and advanced technologies (e.g. efficient sensor networks, electro-optical detectors and unmanned vehicles amongst others) can reveal very helpful.

A promising solution for decreasing the harbour vulnerability is represented by the use of a team of "protecting" Unmanned Surface Vehicles (USVs). Under normal security conditions, the USVs can perform patrolling surveys of the crucial waterways, providing the remote supervisor with optic and/or acoustic images acquired by means of the on-board sensory equipments; instead, whenever a possible "menace" (i.e. an unauthorized vessel or a vessel moving in a suspect way, such as too fast or pointing towards restricted areas) is detected by the global security system, one (or more) of the USVs can be used for "intercepting" the menace by moving as fast as possible towards it, allowing for a prompt determination by the supervisor if the suspect vessel is to be classified as "hostile" or "friendly", without directly exposing any human beings to possible threats.

While the use of USVs is certainly not new, previous experiments where mainly performed in open sea zones or in the absence of other *unknown* moving vessels (see [2], [3] for nice surveys on the topic). However the civilian harbour is an environment characterized by heavy ship traffic, nor the operations of tourist or merchant ships can be modified to accommodate for the presence of the USVs. Therefore the manoeuvres of USVs must not perturb at all the normal harbour activities. Further there is a concrete risk of collision with other vessels, with consequent risks of personal injuries and property damages. Thus, the scenario is particularly different from those where the previous experiments have been carried out.

The above safety considerations have a clear impact on the required characteristics of the overall USVs-based security system. As a first consequence, USVs are required to have good path-following capabilities, in order to be able to follow a reference path with a sufficient accuracy. Moreover, reliable emergency sensory devices capable of detecting incipient obstacles are needed, coupled with the ability and suitable techniques to reactively avoid them. Many of the above topics have been investigated and different interesting results have been recently proposed (see [4], [5], [6], [7]). Despite for some of the above issues consolidated results are not yet available [3], for the sake of the present work the considered USVs will be assumed sufficiently compliant with the above requirements.

Notwithstanding the assumption of almost ideal USVs, their operations still need to be efficiently coordinated, and this

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issue remains to be solved before obtaining an effective and reliable USVs-based harbour security system. In this context, DIST (University of Genova, Italy) and Selex Sistemi Integrati (a Finmeccanica Company, Italy), one of the international leading players in providing large systems for security and defence, are cooperating within an on-going joint research project, on the realization of the so-called Swarm Management Unit (SMU), a tool conceived for supervising the operations of a team of USVs performing (semi-)autonomous surveillance activities within civilian harbours.

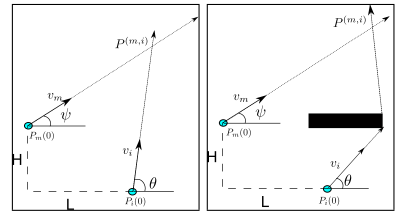
While the details of the SMU project can be found in previous works of the the authors [8], [9] together with a description of the levels of interaction between the SMU and the operator in charge of monitoring the USVs activities, this work focuses on the problem of intercepting detected menaces, before they can reach or harm a particular "asset" (i.e. a site of interest to maintain safeguarded). The solution is composed by two fundamental parts. The first is the on-line selection of the best USV for the interception, once a "suspect" vehicle (thus a possible menace) has been detected: such choice is based on different parameters like position of the menace and its measured (by the harbour radar system) speed and heading, position of all the available "interceptors" USVs and their kinematic characteristics, current traffic conditions (positions and motions of all the other vessel in the area).

Since in the above choice an important role is taken by the position of each USV at the time the "suspect" is detected, it becomes of fundamental importance to determine a-priori the better nominal positioning of all the interceptors, in order to increase their chances of success. Since a vessel may start exhibiting a suspect behaviour when it is at any location (inside or outside the harbour), a menace can in principle "appear" for the first time in any point of the considered area. Therefore the second component for an effective reaction is the off-line optimization of the nominal positions of all the interceptors, to be determined as a tradeoff between two different needs: protecting the asset and guaranteeing a proper area coverage against possible menaces appearing at different locations.

In the present work both the above sub-problems are tackled and solutions optimizing given indexes of performances are proposed and validated through different simulative campaigns. The on-line selection of the most suitable interceptor is first described in section II, as it helps introducing concepts and notations used in the following. Then, the off-line optimization of the position of the USVs is detailed in section III. Section IV describes the methods used for solving the off-line optimization problems, while section V shows different simulative results obtained. Finally section VI outlines the next steps of the SMU project.

II. On-line Selection of the Interceptor

In the on-line selection problem the key issue is to predict which among the team of USVs will be the one with the lowest interception time, in order to be able to guarantee a prompt reaction of the system.



(a) (b)

Fig. 1. The interception problem: **a**) without obstacles (**b**) with an obstacle

In a hypothetic ideal scenario where only the menace and the USVs were present, the problem could be trivially solved by simple kinematic considerations based on the position and motion of the menace and on the position and speeds of the available USVs. However, a civilian harbour is an environment characterized by moving vessels and fixed obstacles that must be avoided.

As a consequence, for every USV, the computation of its predicted time of interception is strictly related with the identification of its minimum-time path to reach the menace, which in turn depends on the contingent traffic situation.

The problem of finding the shortest or the minimal-time path connecting two points in the presence of moving obstacles has been a topic of interest in robotics, machine intelligence, and computational geometry for many years (see for instance [10],[11],[12],[13],[14]).

Such a fundamental problem has been addressed in a previous phase of the SMU project and an efficient real-time motion planner, taking into account the presence of all the fixed or moving obstacles in the area, has been implemented, as inspired by theoretical results proposed in [15]. The planner receives as inputs, every second, the information concerning current positions, speeds and heading angles of all the vessels in the harbour area (extracted from the radar tracks) and can compute a time-optimal reference path driving any USV in any desired location. Of course, as the environment can dynamically change while a USV is following a reference path (because some of the vessels might change their speed or heading), the motion planning procedure is able to generate a new corrected time-optimal path anytime a variation of a radar track is detected.

A detailed description of the motion planner has been presented in [8], [9] and it is therefore here omitted. Only the basic results, useful for understanding the solution of the problem here considered, are here reported for the reader's convenience.

To this aim the simplified problem depicted in Fig. 1 is first considered: given a single USV, say the i-th, moving at its maximum speed v_i, find (if any) the USV heading angle θ enabling the interception of a menace m, starting from a generic position $P_m = (-L, H)$ w.r.t. the USV and moving at a constant speed v_m with a constant heading angle ψ.

By defining the motion of the i-th USV as:

$$P_i(t) \triangleq \begin{bmatrix} x_i(t) \\ y_i(t) \end{bmatrix} = \begin{bmatrix} v_i cos(\theta)t \\ v_i sin(\theta)t \end{bmatrix} \quad (1)$$

and the motion of the menace as

$$P_m(t) \triangleq \begin{bmatrix} x_m(t) \\ y_m(t) \end{bmatrix} = \begin{bmatrix} v_m cos(\psi)t - L \\ v_m sin(\psi)t + H \end{bmatrix} \tag{2}$$

if no obstacles are located between the menace and the USV (Fig. 1.a), the angle θ can be calculated as:

$$\theta = asin\left(\frac{v_m}{v_i} sin\left(\psi + \phi\right)\right) - \phi \tag{3}$$

clearly subject to

$$-1 \leq \frac{v_m}{v_i} sin\left(\psi + \phi\right) \leq 1 \tag{4}$$

where $\phi \triangleq arctan(-H/-L)$. Constraint (4) determines the existence of a feasible solution. If $v_i > v_m$ there is always a solution; otherwise a solution might exist or not depending on the initial conditions of the problem, i.e. the angle ϕ.

In case solution (3) exists, given the angle θ, the time needed for the interception can be calculated as:

$$t^{(m,i)} = \frac{-L}{v_i cos(\theta) - v_m cos(\psi)}, \quad L \neq 0 \tag{5}$$

while the point of the interception is obtained as:

$$P^{(m,i)} \triangleq \begin{bmatrix} P_x^{(m,i)} \\ P_y^{(m,i)} \end{bmatrix} = \begin{bmatrix} v_i cos(\theta) t^{(m,i)} \\ v_i sin(\theta) t^{(m,i)} \end{bmatrix} \tag{6}$$

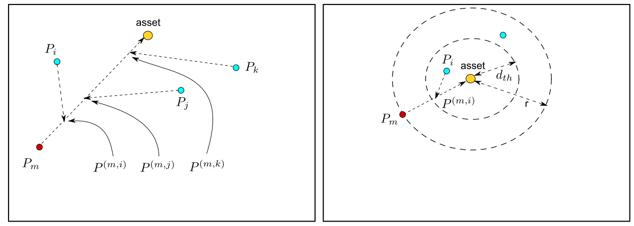
where the notation $(\cdot)^{(m,i)}$ means that the quantity $(\cdot)$ refers to the i-th vehicle intercepting the menace m.

The more realistic situation where at least one obstacle (be it a static or a moving one) prevents the USV from moving on a straight line is sketched in Fig. 1.b. In this case the motion planner first computes the interception points between the USV and the four vertices v_k of the obstacle, by solving the interception problem shown before. This can be done by considering the speed of the obstacle (be it zero or not) in lieu of the menace velocity in expressions (3), (5) and (6), thus the sets of feasible predicted interception points $\{P^{(v_k,i)}\}$ and related interception times $\{t^{(v_k,i)}\}$ can be computed as shown before.

The first step can produce up to four new points $P^{(v_k,i)}$; any point that is not directly reachable because it would lead to a collision with the obstacle is now discarded. Then from any of the resulting point $P^{(v_k,i)}$ the motion planner checks if the menace can be reached with a collision-free straight line. If this is the case, the resulting menace interception point and related time are computed. Otherwise the above procedure is re-iterated from the considered point $P^{(v_k,i)}$, by solving the set of interception problems with the remaining vertices of the obstacle.

This procedure effectively produces and explores a tree of possible alternative collision-free paths. Thus, the A^* method has been chosen to drive the exploration of this tree in an efficient way, obtaining at the end the minimum-time path (even in the presence of many obstacles), together with the resulting optimal $P^{(m,i)}$ and $t^{(m,i)}$.

By now moving back the attention to the original problem of on-line selecting the best interceptor, consider Fig. 2, representing a situation where a menace is discovered at point P_m and is moving towards an asset, located at point $P_a = (x_a, y_a)$. A given number of vehicles $i = 1, \dots, N$ are located in their respective positions P_i. No obstacles are sketched in the figure for clarity, but an arbitrary number of other vessels can be thought to be present in the area.



(a) (b)

Fig. 2. (**a**) Schema of the intercept problem (**b**) with a minimum distance of interception required

As soon as the menace is detected, for every USV, the predicted point of interception $P^{(m,i)}$ and related instant of interception $t^{(m,i)}$ is first of all calculated by the motion planner, as explained before. The problem of selecting the most suitable vehicle can then be simply stated as the following minimization problem:

$$\arg\min_i t^{(m,i)} \tag{7}$$

which can be easily on-line solved, given the availability of all the $t^{(m,i)}$ terms. As a result, other than indicating the best USV for the interception, the SMU outputs also the list of waypoints it has to follow for moving among the obstacles, along the minimum-time path to the menace.

III. Off-line Positioning Optimization

Before going into the details of the off-line optimization techniques, a couple of observations are drawn.

The first one is that if the "suspect" vehicle is consider to appear for the first time anywhere in the area, it could also theoretically be detected when it is already exactly on the asset, making the problem of optimizing the positioning of the USVs formally pointless. Thus, in order to overcome this problem and obtain a meaningful formulation of the problem, it is assumed that any menace is always certainly detected for the first time before it reaches a certain distance r from the asset, which is equivalent to say that no menace can appear inside a radius r from the asset. This assumption is not so unreasonable, as it can be assumed that in the proximities of the asset the navigation be totally forbidden; therefore any vessel trespassing the threshold distance r may be declared as a suspect.

Moreover, notwithstanding the actual interception time of a "suspect" vehicle in the on-line case is heavily dependent on the actual traffic conditions, no other vessels are assumed to be present in the area during the off-line optimization, because their presence is highly time-variant and cannot be a-priori predicted in a reliable way.

Finally, as the velocity of any possible menace is not known a-priori, in the following it is assumed that the menace is always moving with a given upper-bounding speed.

Even under the above assumptions, the problem of off-line deciding the "best" nominal USVs positioning is not as straightforward as the on-line part of the interception problem, always admitting the optimal solution (7).

Indeed such a problem can be considered as a special instance of the so-called spatial resource-allocation problem, which has been studied for many years and has registered interesting results in particular in the field of fixed or mobile sensing networks (see, among the others, [16],[17] and references therein indicated). The goal in such cases is obviously finding out the best location of the available sensing resources in order to maximize a given index of performance, such as the area covered by the network, or the inter-node connectivity, or the confidence level of a measured quantity in the context of adaptive sampling.

In contrast to the above cases, within the harbour security scenario identifying a unique optimal criterion for the optimization process is not as easy. Several *reasonable* alternative strategies can be adopted, in response to the specific index of performance one wish to optimize. For example, to reduce the average interception time, it could be convenient to spread the USVs all around the area, whereas keeping them close to the asset somehow could guarantee an higher level of protection of the asset.

Moving from the above considerations, the proposed solution is based on the following two criteria. First of all the USVs must be in the condition of *always* intercepting *any* menace before it can reach a certain security distance from the asset. As shown in the following, the adoption of such a primary criterion, other than reducing the chances of the menace to harm the asset, provides, as a by-product, an indication on the minimum number of "asset-protector" USVs. All the (eventually available) other USVs can then be employed for the secondary criterion, here stated in terms of reducing the maximum interception time.

A. Primary Criterion: Guaranteeing a Safety Interception Distance

The problem of guaranteeing that *any* menace can be *always* intercepted, before it gets too close to the asset, can be translated into a worst-case-scenario optimization problem. Indeed it has to be guaranteed that, even if the menace is detected in the closest possible position to the asset (i.e. at a distance r), the USVs are always in the condition of intercepting it on time (i.e. before the menace reaches a given security distance $d_{th} < r$, see Fig. 2b).

In order to properly approach the formulation of the above optimization problem, let $P \triangleq \{P_1, \cdots, P_N\}$ denote the set of initial positions of a team of N USVs, while be P_m the initial position of a detected menace m. For any given set of initial conditions (P_m, P), the distance between the interception point related to the i-th USV and the asset can be easily computed as follows:

$$d_i(P_m, P) \triangleq \|P^{(m,i)} - P_a\| \tag{8}$$

It then follows that, for any given (P_m, P), the most suitable USV for the interception is selected as:

$$i^o = \arg\max_{i|P_m,P} d_i(P_m, P) \tag{9}$$

whose corresponding distance between the interception point and the asset is

$$D(P_m, P) \triangleq \max_{i|P_m,P} d_i(P_m, P) \tag{10}$$

By now solving the above problem for any possible P_m (while still maintaining fixed the set P), the worst-case-scenario, i.e. the point P_m leading to the closest to the asset interception point, can be calculated as:

$$D_w(P) \triangleq \min_{P_m|P} D(P_m, P) \tag{11}$$

By finally letting the optimization variable P vary, the optimal positions of the USVs are obtained as:

$$P^o \triangleq \arg\max_{P} D_w(P) \tag{12}$$

By combining all the above relationships, the following formulation of the original optimization problem is obtained:

$$P^o = \arg\max_{P} \left\{ \min_{P_m} \left[\max_{i} \left(\|P^{(m,i)} - P_a\| \right) \right] \right\} \tag{13}$$

whose corresponding distance from the interception point and the asset in the worst-case-scenario is clearly:

$$D^o = \max_{P} \left\{ \min_{P_m} \left[\max_{i} \left(\|P^{(m,i)} - P_a\| \right) \right] \right\} \tag{14}$$

By finally noting that, in case D^o results lower than d_{th}, it means that the considered amount of USVs is not sufficient to always guarantee the fulfillment of the security threshold distance, a simple algorithm is here proposed for determining the minimum number of USVs required for protecting the asset: solve problem (14) for an increasing number of vehicles k (starting from 1) until D^o is made greater than d_{th}. The resulting number k is then the minimum number of required asset-protectors, while the corresponding P^o is the vector of their optimal positioning.

B. Secondary Criterion: Minimization of the Interception Time

The result of the previous procedure is the number k of vehicles that are required to meet the minimum distance of interception from the asset d_{th} and their positioning. If the total number of USVs exceeds this value, the remaining $N-k$ are still subject to optimization. Since the first criterion aims at the protection of the asset and consider the suspect being detected at the closest possible distance from the asset, the USVs are naturally close to the asset themselves.

Thus, the other vehicles should be spread around, in order to have a prompt reaction even if the menace is detected farther away from the asset than the worst case considered in the previous section. To this aim, the secondary criterion is the minimization of the maximum interception time. Indeed it is easy to see that such a criterion allows to spread out the extra vehicles in the area to safeguard, making the team more reactive against menaces detected at any distance from the asset greater than r.

In the following, the new set of USVs is split into two subsets: the first k vehicles with a fixed optimal positioning, as determined by the previous problem; and the remaining $N-k$ ones, whose set of positions $\hat{P} \triangleq \{P_{k+1}, \cdots, P_N\}$ is the subject of the here considered secondary optimization problem.

With these premises, for any given initial conditions (P_m, P), the most suitable USV for the interception is now the one with the lowest interception time, that is:

$$i^o \triangleq \arg \min_{i|P_m,P} t^{(m,i)} \tag{15}$$

whose corresponding interception time is

$$T(P_m, P) \triangleq \min_{i|P_m,P} t^{(m,i)} \tag{16}$$

Then, by again considering the menace in all the allowed positions, the worst-case-scenario can be found as:

$$T_w(P) \triangleq \max_{P_m|P} T(P_m, P) \tag{17}$$

Therefore the optimal positions of the extra-USVs can be found by minimizing the time of interception in the worst-case-scenario; that is:

$$\hat{P}^o \triangleq \arg \min_{\hat{P}} T_w(P) \tag{18}$$

Finally note that, since problem (17) considers all the possible P_m points, the extra USVs are spread out, the farther away from the asset, the bigger the considered area is. The following more convenient formulation of problem (17) can therefore be made, by introducing a proper weighting function $0 \leq W(P_m) \leq 1$ expressing the "probability of detection" of a menace in any particular point:

$$T_w(P) \triangleq \max_{P_m|P} W(P_m) T(P_m, P) \tag{19}$$

In this way the points at the boundaries of the considered area could have a very low weight, as those inside the circle of radius r should have a zero weight.

By also considering the weighting function, the final formulation of the secondary optimization problem becomes:

$$\hat{P}^o = \arg \min_{\hat{P}} \left\{ \max_{P_m} \left[W(P_m) \min_i t^{(m,i)} \right] \right\} \tag{20}$$

IV. Solution of the Off-line Optimizations

Both the off-line optimization problems have been solved using a Monte Carlo approach, coupled with a gradient descent algorithm. About 5000 Monte Carlo samples have been used for each simulation, and for each of them a maximum of 100 steps of the gradient descent have been performed.

During each Monte Carlo run, the team of USVs has been randomly placed in the area, obtaining a particular set P. Then, the area has been discretized using a grid, and for each point the corresponding worst-case-scenario distances (11) or interception times (19) have been calculated. Then, the gradients of the cost indexes D_w and T_w were calculated, by varying one position of the set P at a time, and recalculating the new worst cases. This procedure was iterated until the variation was small enough, or a maximum number of iteration was reached. The final cost values and the relative positioning were saved and the best ones selected by comparing the different results of all the Monte Carlo runs.

A special remark must be done for the weighted problem (19): it could happen that an USV, randomly placed in a zone where $W(P_m) = 0$, is never selected as the most suitable vehicle for interception. Then the values of the gradient corresponding to the position of that USV have always a value of 0, which implies that the USV is never moved by the optimization procedure. In order to solve this problem, whenever the optimization algorithm finds that one USV is never selected for the interception, i.e. is *unused*, that USV is moved in a point in-between the asset and the point corresponding to the current worst case.

Naturally, since a numeric method has been used, all the solutions are affected by the discretization process and the numerical precision.

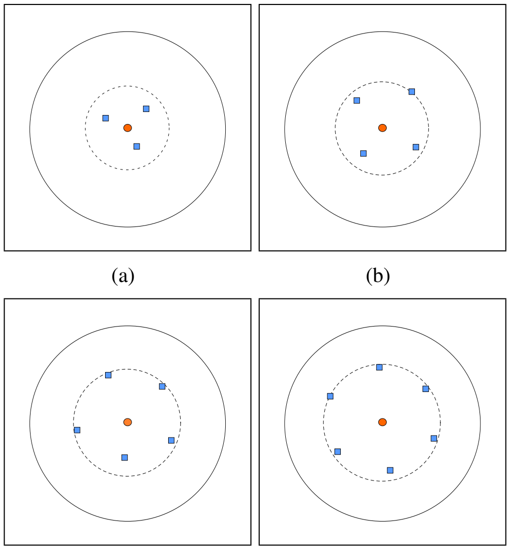
V. Simulative Results

This section presents the preliminary simulative results obtained by solving the two off-line optimization problems. In order to better validate the obtained results, a simple squared area has been used in all the presented simulations. Cases with irregular borders (such as fragmented coast lines) or harbour infrastructures (such as docks) are not found here for two reasons: i) in this first phase of the evaluation of the algorithms, simpler cases are much easier to understand and validate; ii) since, in the presence of fixed obstacles, the same menace should *somehow* avoid them, a further effort has to be spent for determining (at least on a probabilistic basis) the path expected to be followed by the menace. This last issue is currently under investigation and is actually a very challenging part of the future works.

In all the following figures the orange circle represents the position of the asset, while the blue squares represent the positions of the USVs, as they result from the considered optimization problem.

As for the asset protection problem, simulations have been performed by varying the security threshold d_{th} (the dashed circle) of a given asset with a given forbidden region $r = 200m$ (depicted with the solid circle, see Fig. 3). Menaces are supposed to move at a speed of $20m/s$, while USVs are considered slower, with a velocity of $15m/s$. As expected, the minimum number of required asset protectors is strictly dependent on the value of d_{th}.

As for the secondary optimization problem, more simulations have been performed by varying different parameters. In all the considered cases, in order to emphasize the positioning of the extra-USVs only, a point-wise asset has been considered



(a) (b) (c) (d)

Fig. 3. Different optimized results of the asset protection problem obtained by varying d_{th}: (**a**) $d_{th} = 86m$ (**b**) $d_{th} = 96m$ (**c**) $d_{th} = 110m$ (**d**) $d_{th} = 120m$

with a very low d_{th} threshold. In this way the solution of the first optimization problem leads to a single asset protector located on the asset (and not depicted in figures). The area of interest is a square grid from coordinates $(-1000, -1000)$ of the bottom left point to coordinates $(1000, 1000)$ of the top-right corner.

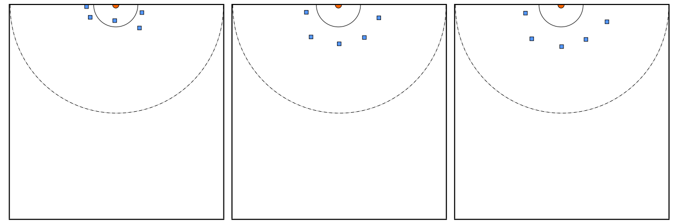
The first simulation, depicted in Fig. 4, shows the different results obtained with the asset placed in $(0, 1000)$, by varying the velocity of the USV. According to intuition, the slower the USVs are, the closer they need to be to the asset. The following weighting function is used:

$$W(P_m) = \begin{cases} 0 & d < 200; \\ (d-200)/1000 & 200 < d < 600; \\ (1000-d)/1000 & 600 < d < 1000; \\ 0 & d > 1000 \end{cases} \quad (21)$$

where $d = \|P_m - P_a\|$ is the distance of the considered point to the asset. In this and all the following simulations, the dashed circle represents $d = 1000m$ from the asset, so outside it is $W(P_m) = 0$.

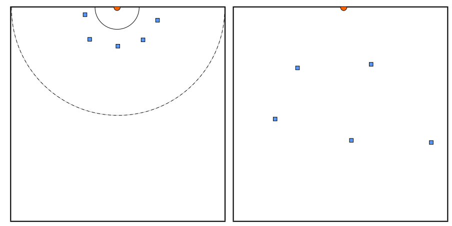
In the second example, shown in Fig. 5, the effects of the weighting function $W(P_m)$ can be seen. Menaces and USVs are here supposed to move at a speed of $20m/s$, and $15m/s$, respectively. While on the left the use of the previously defined $W(P_m)$ is shown, on the right side the results have been obtained by setting $W(P_m) = 1$ for each point. As expected, not weighting the points makes the vehicles spread even more towards the points farthest away from the asset, as they are the ones with the highest possible interception time.

The simulation of Fig. 6 (again performed with the above weighting function and with speeds of $20m/s$, and $15m/s$ for menaces and USVs respectively) shows instead the effects of the number of available USVs.



(a) (b) (c)

Fig. 4. (**a**) USV with speed of 5m/s (**b**) speed 15m/s (**c**) speed 25m/s



(a) (b)

Fig. 5. (**a**) with radial $W(P_m)$ (**b**) with $W(P_m) = 1$

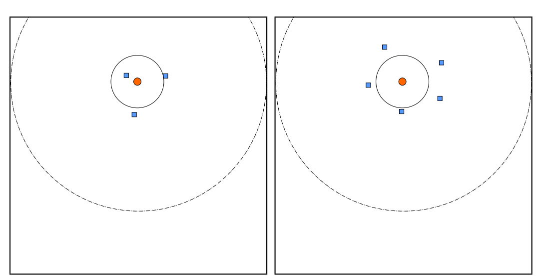
Fig. 7 instead depicts the results obtained under the same conditions of the previous one by using 6 USVs, and the effects of the position of the asset with respect to the zone of interest. Indeed, if the asset is in an open sea zone, the USVs will be spread all around, while if the asset is on the margin of the zone, or even in one corner, the USVs are positioned in front of it.

The last simulation (see Fig. 8) shows a perfectly symmetric case, where the asset has been placed at the center of the zone and a radial $W(P_m)$ has been used as weighting function. As it could be expected and according to common intuition, the procedure places the USVs in a circle all around the asset.

VI. Conclusion and Future Works

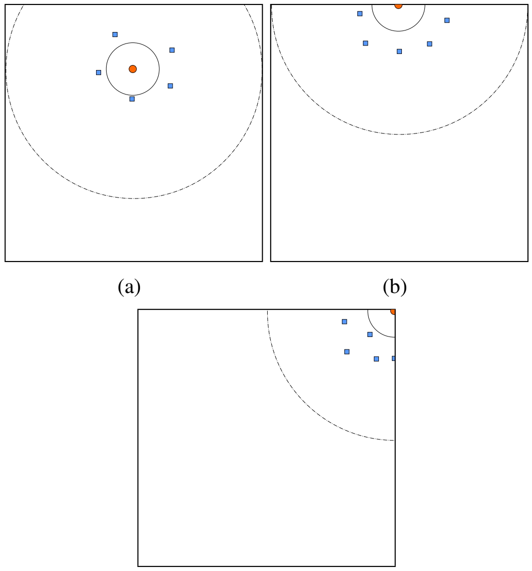
This paper has presented the latest research results regarding the Swarm Management Unit project, a joint effort between Univ. of Genova and Selex Sistemi Integrati, aimed at developing a tool conceived for supervising the operations of a team of Unmanned Surface Vehicles performing surveillance activities within civilian harbours.

In particular, a solution to the problem of intercepting menaces has been proposed here, and will be shortly integrated



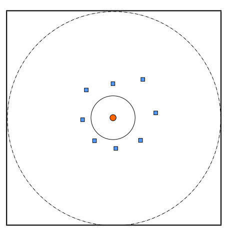
(a) (b)

Fig. 6. (**a**) with 4 USVs (**b**) with 6 USVs



(a) (b) (c)

Fig. 7. (**a**) 6 USVs with asset in $(0, 500)$ (**b**) asset in $(0, 1000)$ (**c**) asset in $(1000, 1000)$



(a)

Fig. 8. (**a**) 9 USVs with asset in $(0, 0)$

into the SMU. The system is made up of two main parts: the first one is responsible of on-line selecting the predicted time-optimal vehicle for the interception, the second one is dedicated to the offline optimization of the USVs' positioning.

Current works are focused on simulating the cases with fixed obstacles, while future ones will tackle those with multiple assets and/or multiple menaces. Finally, sea trials to be held in La Spezia's harbour have been planned by Selex Sistemi Integrati for Summer 2010, where the latest version of the SMU will be tested.

ACKNOWLEDGMENT

This research was partially funded by EU FP7 project "CO3AUVs: Cognitive Cooperative Control of Autonomous Underwater Vehicles", under Grant Agreement n. 23 1378.

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