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Harness: A Robotic Swarm for Harbour Security

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ABSTRACT

This paper is dealing with project aimed at the development and realization of a novel marine technology, suitable for missions like protection of civil and military ships against terroristic attacks and harbour security. HARNES (Human telecontrolled Adaptive Robotic Network of SensorS) project is actually in progress in our laboratory and it is regarding an underwater robotic swarm. This system is based on a number of cheap autonomous underwater vehicles (AUV) organized with swarm rules able to perform very different task. The key points of the HARNES project are: the development of a novel underwater acoustic channel with very high performances in routing and data throughput capacities and the design of a reliable swarm rule-based control system with an interface towards a supervisor operator acting as a priority definition arbiter. Therefore it is based on the fusion of the concepts of swarm intelligence and multihop communication networks to cope with the severe problems in underwater complex tasks. Human in-loop supervision can be exploited owing to an increase in communication performances and to a redefinition of the teleoperation concept. The high efficiency that the communication can reach makes the system especially efficient in exploring large volumes of water in relatively short times. Moreover we are experimenting some conventional and not methods for localization of the swarm.

1.0 INTRODUCTION

This work describes a multipurpose underwater robotic system to be used for exploration, surveillance and threats preventing of underwater marine coast.

This system is a school of autonomous underwater vehicles (AUV): a swarm. Its development is currently work in progress in our laboratory in the framework of the HARNES project (Human telecontrolled Adaptive Robotic Network of SensorS) . The object is the realization of an underwater multi body robotic system able to perform tasks in a faster and reliable way as compared to a single vehicle. A swarm is a more robust system with respect of a single machine: if a machine get lost the mission will be performed the same. A school of robot whose behaviour is like fish, can be equipped with a general and a more specific mission payload, to perform security surveillance. When a scout go to the surface the data will be transmitted, by satellite connection, to the server, saving the cost relative to a ship use.

The key points of the HARNES project are: the development of a novel underwater acoustic channel with very high performances in routing and data throughput capacities, the design of a reliable swarm control system based on a balance of centralized and distributed control and the development of an interface with the operator able to permit an interaction with the swarm as a whole. The project includes a demonstration with a limited number of physical vehicles and with a larger number of simulated ones.

Harness project is aimed at the integration of the individual, collective and communication control levels in a multi robot system in order to ensure the full operation capabilities both from the point of view of the network efficiency and of the aspect of mission efficiency (adaptation to the environment). Natural examples (See Figure 1 and 2) represented a couple of typical situations.



Figure 1: Cylinder shape obtained by the internal rules of a swarm, usually reaction to a threat by a hunter.

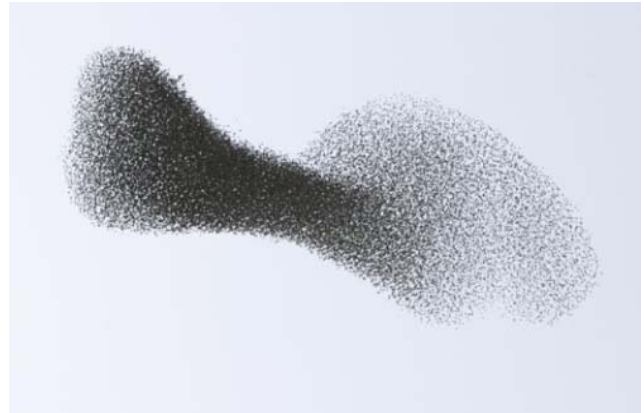


Figure 2: Adaptation of a bird swarm to environmental need (food hunting)

In robotics, it is common to refer to this kind of organisation with the term of “swarms”.

The use of underwater robotic vehicles in oceanic surveys, inspections, pipe and cable tracking, has been well established in the field of marine engineering since many years ago [1]. Today surveillance of ports and of other maritime environments, is assuming an increasing importance for naval and customs services [2]; also a nuclear waste pool too has been considered as an interesting target to be controlled by autonomous underwater vehicle (AUV) [3]. Marine robotics technology has undergone a phase of dramatic increase in capability in recent years [4] and many autonomous underwater vehicle systems have moved from the prototype stage to scientific, commercial, and military uses. To make sense, by an economical point of view, an AUV must be a real cost alternative to other available technologies, such as manned submersibles, remotely operated vehicles (ROVs) and towed instruments led by ships. The benefits of using autonomous data gathering have to be compared against the difficulties faced by AUVs in power, sensing, information processing, navigation, and control. In fact untethered operations impose severe restrictions on power consumption and present challenging problems in intelligent control. Navigation is one of the principal challenges that limits our capability to use AUVs; the continuous knowledge of good navigation information by a control center is essential for safe operation and recovery of an AUV; moreover the data gathered by an AUV must be accurately referenced in space and time. Having a good estimate of one’s location is critical for manned and unmanned vehicles, but it is particularly important for autonomous vehicles as unsupervised decisions are made based on the location estimate. Furthermore the quality of the data collected is directly dependent on how well measurements can be referenced to a geographic location.

An underwater vehicle may carry a large variety of sensors depending on the dimensions, the technology of the vehicle and the requirements of the mission.

In a swarm the robots operate with a common objective and sharing the job workload; the lack of one member can be easily taken care of by redistributing the job among the others. This feature is especially useful if we consider as the swarm task the surveillance of submarine sites. See as example figure 3. Protection of ships against passive (i.e. mines) and active threats (underwater attacks by scuba divers) can

be also a task for a robotic swarm. What makes swarms especially is their capability to fill and control large volume of waters by means of a network of cooperating sensors and their capability to move in the most interesting zones, increasing density where there is a major need. They are also easily transportable and deployable in medium or large number of elements.

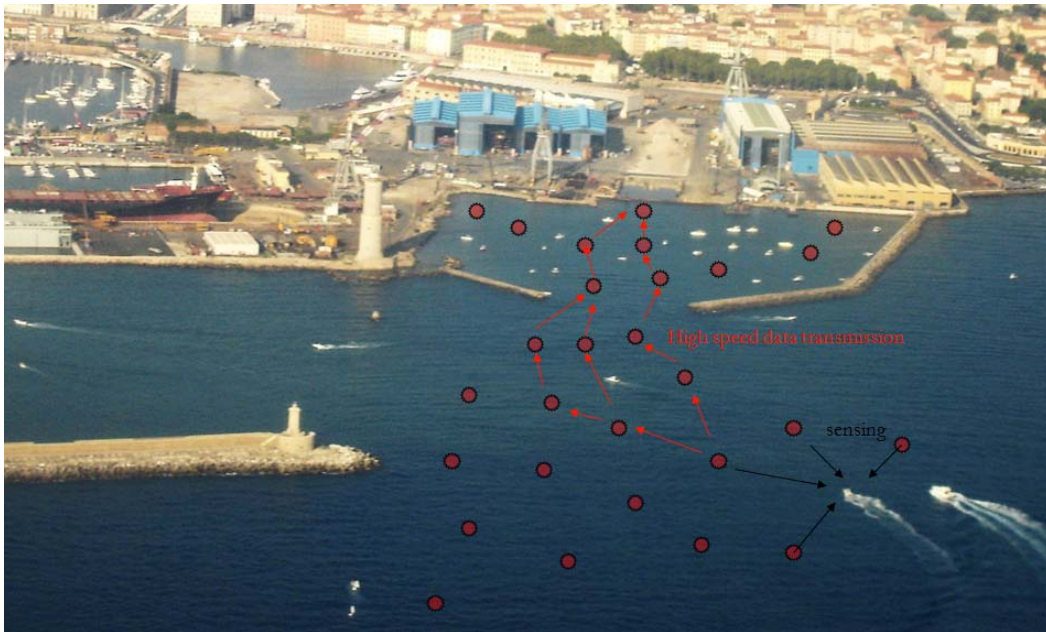


Figure 3: An example of using a swarm robot for harbour surveillance.

Moreover a swarm can be considered as a whole thus offering the advantage of a simple way of interfacing with the human end-users, overcoming the problem of separately controlling a large number of individuals. The geometrical distribution of the members of this system is flexible and adaptable to the task and environmental characteristics. In the underwater world a severe limitation to our communications technology is perhaps the main drawback: the physical medium only permits acoustical channels, since electromagnetic waves are rapidly damped. Also the acoustical technology is heavily affected by a fast decay in the signal bandpass as soon as the distance increase, also for limited ranges. This limitation can be overcome by a suitable and intelligent spatial distribution of transmission nodes (the swarm members themselves), allowing an enhanced throughput of data through logical and physical routing. One of the aims of the project is the creation of an adaptation capability among individual, collective and communication behaviors of the swarm in order to maximize the performance of the system.

Therefore a desirable issue is the system ability to adapt itself to the environmental characteristics, with special reference to the problems arising in the communication inter-individual and between the swarm and the human. These aspects are both related to the communication channel and to the geometrical distribution of the multi robot system [2]. In the underwater world there is an evident limitation to data throughput and temporal delay caused by the physical medium. The swarm will communicate also by optical signals but depending on the salinity, the turbidity, the presence of dissolved substances that change the colour and the transparency in different optical bands the bandpass can be heavily affected. Therefore communications can take place with greater or lower speed in the optical or acoustical domains, with different delays, attenuations, angular distributions of the radiated power and so forth. In other words there are almost continuous modifications of the acoustical and/or electromagnetic channel travelling from different areas, often quite close each other.

The multi body system can react to these modifications both modifying the parameters of its transmission "organs" and modifying the physical dispersion/geometry of the system itself. If the mission of the system asks for a greater dispersion in order to maximise the volume (See Figure 4) to be explored the communication bandpass could be slowed down and/or the main stream of the information can be differently balanced among the available channels (currently optical and acoustical) or possibly to Radio Frequency (in case of fresh waters for instance). If the priority is on the risk that the amount of exchanged information becomes inadequate to ensure the correct behaviour of the multi body, the system itself can physically react changing geometry despite of the drop in performances on the assigned task.

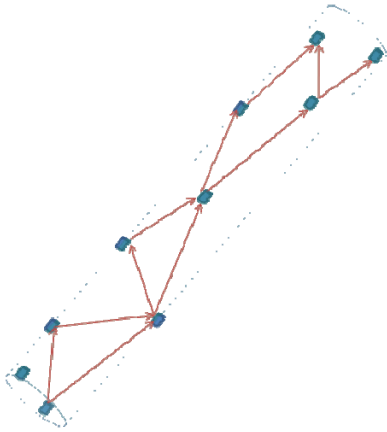


Figure 4: Pipe configuration for fast exchange of data.

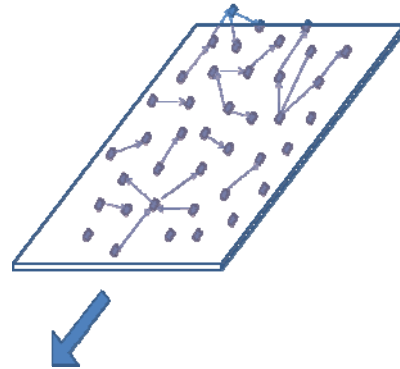


Figure 5: "Plane" geometry for parallel operation.

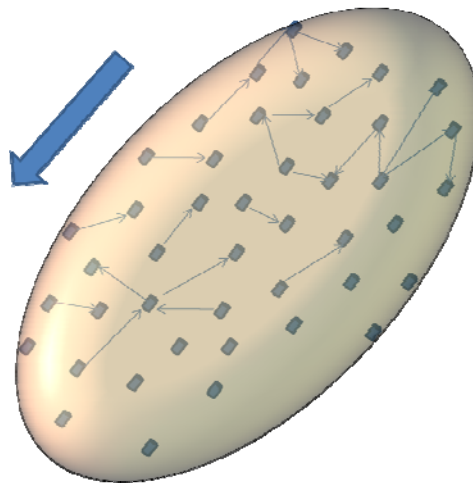


Figure 6: "Ellipse" is a quite typical shape used in fish schools typically aimed at giving the most impressive "footprint" to possible predators, but it is also the result of the dynamical processes of arrangement of the school itself.

2.0 THE PROTOTYPE

In Fig. 7 the Venus prototype, realized in our laboratory, is showed. Its characteristics are the following:

Max depth 100m; Max speed 2 Knots; Weight about 20 Kg; Autonomy 3hrs ; Dimensions 1.20mX0.20m diameter.

Standard sensors include a stereoscopic camera, sonar, accelerometer, compass, depth meter, hydrophones side-scan sonar.



Figure 7: Low cost Venus AUV.

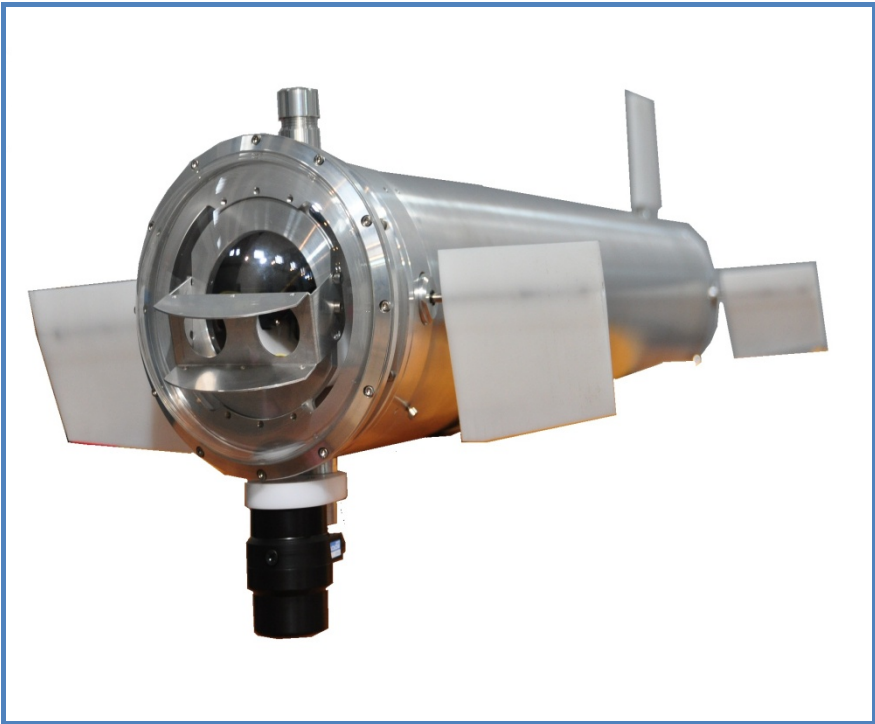


Figure 8: Low cost Venus AUV frontal view.

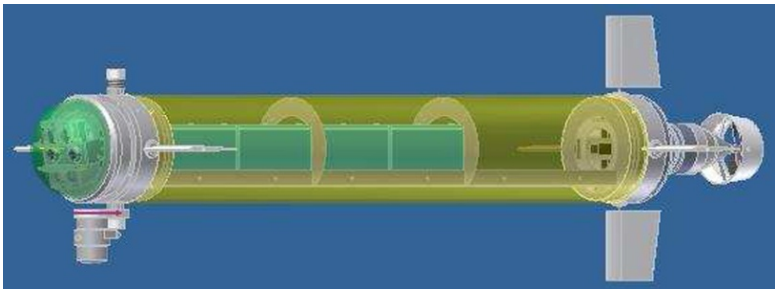


Figure 9: Venus during the project.

We are dealing with a system thought as a swarm of about 20 object. The distance between robots are between 1 meter and 50 meter. Therefore the maximum distance possible between two robots is about 1000 meters, as very particular alignment case; the average value of the distances is about ten meters. maximum speed should be about 2 knots.

3.0 THE TECHNOLOGICAL CHALLENGES

The swarm control must balance the different needs of the operator on one side (e.g. the mission task) and of the single elements of the swarm on the other (e.g. obstacle avoidance, loss of communication link, etc.).

This equilibrium can change depending on the assigned tasks, the survival risk associated to the operation of each robot and the risk associated to the loss of connection with rest of the swarm. Approaches currently under study to this aim include neural network techniques, fuzzy logic and genetic algorithms.

In the swarm there is no central brain, each individual must possess an intelligent local control system capable to control its route on the basis of the available data. These data will be different depending on the position inside the swarm, the data propagation speed and, in special cases, by the role of some individuals (e.g. a scout going on surface for communication and localization by GPS).

A possible quite efficient way to achieve this result is to organise a number of cheap, small units able to change their relative cooperation modes, geometries and other functional parameters by means of relatively simple rules that every member of the “swarm” has to follow (the Boyd swarm is a very famous example). Typical objective of these rules are the maintenance of group coherence, the capability to follow a common target, the ability to avoid foreseen or unforeseen obstacles, the ability to share and use data perceived by all the group member. All these group behaviours allow in an implicit way, usually called “emergent behaviour” to fit at best with the surrounding environment.

An underwater vehicle may carry a large variety of sensors depending on the dimensions, the technology of the vehicle and the requirements of the mission; one of the role of the above sensors is to provide the vehicle controller with a sufficient precision during the navigation.

It is well known as the swarm control level and the local individual control level can originate conflictual situations relevant to the optimisation of global and local goals. The choice of the right strategy to manage and synchronise this multilevel adaptive system is still under investigation and will be explored in a much greater detail during the project development, but it clearly involves the definition of rules in explicit (expert system) or implicit (neural networks) form and should be capable of on-the-job learning.

In general, the test case of Harness is based on an underwater swarm of simple autonomous mobile communication nodes with sensing capabilities for security monitoring. The global control architecture will be built around three basic issues: the human supplied goals, the internal operational rules, ensuring stability and coordination of members behaviour through the communication network, the emergencies and automatic answers of the single machine.

The control of a system composed by a large number of mobile robots operating with a common objective and sharing the job workload without a specific and individual programming have to take into account the paradigm of emergent behavior. This is an unforeseen common “behavior” [3-5] of the multibody system that derives from the rules originally programmed with respect of specific situation (alarms, obstacles, etc...). Many studies have been carried out on this issue, but presently there is no general solution to address and program the arising of emergent behaviors.

The starting point, that is also our objective, is to consider the multi body swarm as a unique device with behavior and reactions of a single creature. This means that every part of the intelligence of the swarm

(communication management, low level control, high level control, HRI) must be strongly integrated and dependant by the other parts to ensure a correct operation. Because it doesn't exist a "central brain", each individual must own the whole capability intelligence system, whereas the data available to the single can be different depending on the position inside the swarm as we have seen. This approach implies that, as in the natural evolution, a part of the foreseen research is focused on the efficiency of algorithm swarm whereas another part must be specialized to the peculiar environment where the system will be hosted in its normal operation.

Scientific and technical challenges can be summarized in:

- Individual control of small vessels;
- Swarm control as a whole, taking into account the different level of needs;
- Identification of minimal sensor sets for specific tasks;
- Localization of individual small vessels with respect to their operating environment as well as with respect to other vessels of the swarm;
- Establishment of communication methods characterized by fault tolerant algorithms, high frequency carrier, controlled distance modulating power;
- Exploitation of the communication network for localization purposes;
- Overcome of the problem of low data transmission bandpass, associated to almost every signal propagation inside the marine water;
- Drastically improve the monitoring capability for a number of tasks requested in sea coastal areas (namely pollution control, biological control i.e. in fishing aquaculture, intrusion surveillance, rescue operations);
- Get an easy and fast supervised control by a human operator, to introduce high level decision capability in the loop; and
- Optimize the system behavior in different environments to improve the robustness and the reliability of the system.

Presently research topics in the area of underwater swarms are the following:

- Algorithms for swarms of robots allowing scalable (multiresolution) perception (during exploration, searching, or monitoring) of sea areas;
- Active and passive localization of individuals with respect to neighbour vessels and of the whole swarm with respect to the environment; and
- Dynamical communication and routing protocols, which explicitly consider and adapt the current knowledge about the physical positions (including momentum and orientations) of individual nodes.

Some technological goals that should characterize the design of an underwater "swarm oriented" robot:

- Very agile;
- Low cost;
- Endowed with equipment for an easy, multi-level communication with its neighbors; and
- Endowed with sensing equipment suitable for a "swarm" perception.

Other more typical features are:

- Mechanically robust;

- Equipped with sufficient computational power for any level of autonomy;
- Equipped with efficient batteries for electrical power; and
- Supplied with robust motion control sub-systems;

The expected results are:

- The realization of novel and advanced algorithms that allows the communication on a multi hopped network based on a multiple transmission system (acoustical / electromagnetic);
- The realization of an adaptive intelligent system that can manage all (or a great part of) the requested features of the reference environment; and
- The realization of a demonstrator based on the realization of a physical platform that incorporates all the software developments carried out during the project.

3.1 The Problem

Four topics are identified as key elements of the architecture: Communication, Control, Localization, Teleoperation. Each of them will keep busy many people since long time so we shall give just a sharp look on their application in Harness project.

The Swarm can be viewed as a wireless network of mobile nodes. So far it is able to adapt for different needs depending on the physical arrangement of the nodes geometry. As example the swarm can assume the pipe configuration, (to transmit high speed data along relatively long distance), disperse configuration (to enlarge the surveillance area with low band pass) or a particular configuration to increase the internal (to the swarm) bandpass in order to allow processing like data fusion coming from many sensors concentrated on the same target (Enhanced Data Fusion mode). In Communication we are trying to use the following signal categories.

- Acoustical active signals
- Acoustical passive signals
- Electromagnetic (optical) active signals
- Electromagnetic (optical) passive signals
- Electromagnetic active signals (only for surface communication)

There are also other kind of possible signals (like for instance the magnetic ones) and promising progresses are on the way, but the studies on them by our group are still at preliminary stages.

A lot of job also is in progress on the transmission protocol aspects.

The control system for 3D swarms also in underwater environment is already a well treated topic in literature; starting by the fundamental work of Bonabeau [13].

The control of the swarm is based on the management of three control layers: Communication control, Swarm control, and Individual control; an Arbiter will take care of the choices in case of conflicts among the different layers. The name of the different layer are quite self explaining. The Swarm Control, basically, has to generate the primitives sent to the Individual Control for the planning of the trajectories.

Primitive is a rule that can deal with the individual control.

Just as example we shall dial a little bit more on the localization problem, but each one of the poreceeding topics can be a research field.

To perform a navigation plan it is mandatory to know the position of the robot with respect to a reference system and self-localization of an underwater vehicle is particularly challenging due to the absence of Global Positioning System (GPS) reception owing to the well known attenuation of electromagnetic waves in conductive media.

Localization and (eventually) mapping are the essence of a successful navigation in autonomous mobile platform technology and are fundamental tasks in order to achieve high levels of autonomy in robot navigation and robustness in vehicle positioning and values of the data. Robot localization and mapping is commonly related to cartography, combining science, technique and computation to build a trajectory map that reality can be used to correlate spatial information with the data collection. Therefore an autonomous robot should be able to construct (or use) a map or floor plan and to localize itself in it.

The introduction of Simultaneous Localization and Mapping (SLAM) technique has become the key enabling technology for mobile robot navigation. SLAM joint the problem of acquiring a spatial map of a mobile robot environment while simultaneously localizing the robot relatively at this model.

The localization make sense not only for the localization of the robot itself but also to reach some objective, as example some sensor posed on the sea floor and gathering the data or some specific position in the sea to monitorize [5], [6]. Therefore we shall distinguish different scenarios for localization of the robot.

Based on these statements we shall give now a sharp look to the different used methods to localize single robot machine into the water, relatively and absolute to reach a proposal for our swarm.

The localization problem is divided in three different categories corresponding to three different working scenario. Precise localization (the swarm working close the shipwreck), rough localization (the swarm is travelling towards the objective) and relative localization (the relative position of the swarm members).

We distinguish the problems the localization for a single robot machine and a swarm because they are heavily separate: Localization of a single entity is a problem relevant to understand a metric of the space, possibly realized only by a sequence of reference points, and to place the entity in relations with the established metrics or with the reference points. Localization of a swarm underline the different techniques that can be used together with the different information that can be gained. Moreover cooperative localization can be showed, if the swarm recognize a landmark putting together different picture taken by different robot. Also passive sound signature recognition can be considered as cooperative localization.

The localization concept does not necessarily coincide with the definition of a reference frame metric and Cartesian; for many animals, for example, localization may be related to different types of metrics such as that linked to research sources for something that is critical for their life (or for the swarm that is a more important economy). Food for the animals is the equivalent of a source of pollution in the mission of our swarm for the environment monitoring.

In this case we talk about identification on a physical field with gradients of arbitrarily complex shape; our position is therefore referred to the smell, great or little, of our reference parameter (i.e. oil presence) relative. We can move toward the higher value of the field, the oil wake to reach the source. In this case the geometric or geographic location, is meaningless for the purpose of the mission, but when we have to communicate to an human supervisor once again is important to the concept of geographical location.

Of course to perform this kind of localization related to a parameter the swarm must to be able to get the right parameters value, i.e. if we locate by the smell we must have a nose.

Another method, used by humans and animals, of tracking system is represented the construction of a map of the environment fixing in the memory a set of recognized items that are connected to each other. This kind of items are very general and it is not necessarily geographically (although it is now by far the most important type); moreover the human mind often does not work geographically. Rather, the mind associates the recognition of a number of characteristic features (houses, streams, odors) of other distinguishing features (other homes, streams, smells, plants) that have a characteristic of "proximity" with those who preceded them. The "map" thus becomes a multidimensional set of associations that allow you to switch gradually from a certain place (starting location) to another place (intermediate location of arrival) via a route typically (but not necessarily) geographically.

The numbers of dimensions of this approach is very relative because it depends on many variables some of which are difficult to measure. Moreover for a human this number interested only in relation to other needs (e.g. the time it takes to go from one place to another).

The geographical approach supported by the geometric metrics it is a powerful tool that humans have developed and which allowed him to perform a very big step forward compared to most other creatures, but is not essential to the success of a mission and it is not the only one.

In the case of a swarm, or of a non rigid single machine exist also the localization relative to the other members of the swarm and a collection of techniques and paradigm can be used. Because the shape of the swarm is very important for the mission the relative localization has the same importance of the absolute; we can use the same conceptual categories defined by absolute location once again not necessary geometric. As example the kinesthetic sense of human body is working with a sensitivity to muscle extension that is detected by non-metric variables; the brain provide later to relate these variables to make positioning the body in the world around them and then to a geometric structure.

However, leaving the pure conceptual world, and going on to basically concept we can say that its location can ignore these issues and extending beyond the location of geometric type. Now we can discuss about some kind of localization in metric form.

The more easy to understand is the metric localization using a Cartesian frame system, and in this contest the simplest form of localization is the open loop estimation; it has the mean of estimate position based on expected results of motion commands. Therefore no contribution from the sensor is required and no feedback is calculated.

Without an external reference, like for example an acoustic beacons at known positions, the vehicle has to rely on proprioceptive information obtained through a compass, a Doppler Velocity Logger (DVL) or an Inertial Navigation System (INS). [6] To this, totally internal to the robot family belong one of commonest method, the dead reckoning, that is the most common methods after open loop.

The information that the robot gather can be divided into two kinds; idiothetic and allothetic sources. That has the mean of internal and external sensor source data; if a robot is counting the number of wheel turns this is internal source.

The allothetic source corresponds to the sensors of the robot, like a camera, a microphone, laser or sonar. A typical problem of this last method is "perceptual aliasing"; this means that two different places can be perceived as the same. For example, in a building, it may be impossible for to determine your location (sometime also for human solely with the visual information, because all the corridors may look the same.

The most common dead reckoning sensor is the INS. An INS measures the linear acceleration and the angular velocity of the vehicle using three accelerometers and three gyroscopes. Typical underwater external sensors used to correct accumulated errors from the integration of the INS measurements, are

Doppler Velocity Log Sensors (DVL), Ultra Short Baseline (USBL) and Differential Global Position Systems (DGPS/GPS); this last only in the case the vehicle is operating at shallow waters and can come out of the water to fix (and eventually communicate) the position.

Independent of the quality of the sensors used, the error in the position estimate based on dead-reckoning information grows without upper limit. Typical navigation errors some per cent of distance traveled for vehicles traveling within a hundred meters of sea. Lower errors can be obtained with large and expensive INS systems, but for vehicles relying only on a compass and a speed estimate can be higher than 10%, after one hundred meter. The error can be reset if the AUV comes to the surface by GPS, but sometimes this is impossible (under ice as example) or undesirable (security operation) [7]. The use of beacons to form a Long Baseline (LBL) array limits the operation area to a few square kilometres and requires a substantial deployment effort, to pose the beacons, before operations, especially in deep water. This reduce the advantages of AUV and required an expensive ship to support the operation.

Other methods employ the use of landmark. If we use external references the localization problem, like humans, we have to deal with their definitions and position on a map (metric or not). Any kind of landmark is subject to classification based on its attributes. Moreover the identification of a landmark often suffer of ambiguities problems, owing to the multiple solution of the associate equations.

A set of feature location position estimates can basically be thought of as a map. The challenge is to combine INS/dead-reckoning and other information with sensor observations of features to build a map, locally or globally referenced.

A more modern idea consist in to match measurements of one or more geophysical properties, such as bathymetry, gravity, or magnetic field, to an a priori environment map. If there is sufficient spatial variation in the parameters being measured, there is potential to reduce navigation uncertainty. Also the turtles migration is monitored by magnetometers, measuring the earth's magnetic field variations. However often these techniques requires a priori map of the environment that is not available. The marine turtles migrations are monitored by three axis magnetometer, but the resolution is 35 nautical miles. [8, 9]

As we have said the localization for a swarm we suppose problem can be divided in three tasks:

- 1) Absolute localization, that has the mean of localization with respect of a fixed reference system, of one member of the swarm (AL).
- 2) Relative localization of a member with respect of the others members (RL).
- 3) Relative localization of a member with respect of the others members, but only neighbours; we call it immediate relative localization (IRL) and its meaning will be cleared later.

Different methodologies are required to solve the three tasks. In agreement with the swarm philosophy each element must be able, if connected with the other, to perform the localization job. Attention must be posed in the last affirmation. We mean not that each element must do all the job; often there is no need to know all machines position but we must be able to do using all the internal data, the external data communicate by the other elements and the external data measured by the robot, inclusive that deduced by environment observation.

While the first two categories are quite self explaining the usefulness of this further categorization (IRL) was designed to obtain a rapid response to variations in the environment of the entire swarm. If the system should await a thorough knowledge of its internal structure before deciding on the type of response of each unit of the swarm the reactions time would be too slow, compared to the dynamics of environmental phenomena and the system has low chances of success in its mission. It is well-known the recognition mechanism used in the school of fish that allows them to change the position of the entire school in a very quick time just looking the movement of the neighbours. In principle also ILR is more easily achieved

with simple signals (which are very fast and then be transmitted) based on physical fast transient, and possibly using a rapid propagation of fields such as optical. Later, if necessary, the swarm can compute the relative position of the whole system.

To address the localization problem to our swarm we define three types of operative scenario:

- 1) The swarm is in open water going to the objective; eventually monitoring is allowed. This should be the simplest localization situation, one element of the swarm is on the surface and fix position by GPS. The relative position of the other members is measured by other methods. Swarm shape is depending on the job.
- 2) The swarm is operating very close to the objective. The shape of the swarm is able to maximize the area covered just close to the objective. Landmark of the objective are useful for localization.
- 3) The swarm is operating in a structured environment like arbor. This is the most difficult task because now are the aim of the mission (surveillance, pollution monitoring..) that determine the swarm movements and the shape must be take in account the constrained by the environment. In fact in such conditions some shape could be not allowed. As example in a arbor could be necessary to minimize the volume occupied by the swarm to avoid collision with the ship or similar, and the use of acoustic beacon could be convenient.

In these three different scenarios the strategy of movement and localization could be completely different.

It should be stressed that if we have a constellation of at least four vessel we can derive the relative position of the others by GPS calculation methods. For example if we have three or (better) four vessels on the surface they can be positioned by GPS. Later, using the communication system, we can obtained (by many methods) the distance between one more vessels and the “constellation”. Using the same mathematical calculation of the GPS system we can absolute localize the whole swarm. The vessels surface (That can be substituted by little boats) have the advantage that can carry a high band pass using laser communication system, owing the easy transmission vertical channel; in fact the collimation problem between vessels, in this case, can be partially avoided owing the transmission direction that is quire vertical so the collimation between laser and receiver is much more easy.

If we have not the surface vessels we can calculate the Relative Localization solving the distance equations; however to select between multiple solutions we need some more information. A flash, as example, to discriminate direction from which the signal is arrived. Another methods to eliminate multiple solutions could be to perform two measurements with a known movement of the swarm between them. In this case the second family of solution determinate the cancellation of some solutions. In fact if I know the direction of the movement the rotational and also some specula symmetry is broken.

Really speaking this is valid much more in open sea; for an harbour the USBL solution seems to be the more practical; in fact it can be employed in a fixed structure without use of service ship.

Teleoperation represents one of the most important targets of the research line. In underwater environments there are delays and transmission speed problems, therefore the man-in-the-loop concept needs for particular cares. In addition the classical approach of Teleoperation, an external sequence of orders, with a metrics inside, is not the best way to cope with a Swarm paradigm.

Teleoperation it is usually intended to interact with the swarm to modify high level objectives. Nevertheless, because the swarm control is conceived to have a limited or null interactions with external “orders” we used the trick to process the requests of the supervisor by translating them into “needs”. These “needs” becomes internal behavioural rules of the swarm itself; after this translations they are “implanted” in every member of the swarm through the Communication Network modifying and superimposing themselves to the previous swarm reactions. Therefore we call this new concept “TeleCooperation”.

In the case of discovery of intrusion you may pass to the next phase of human decision.

4.0 EQUIPMENT REQUIRED

Equipment to perform these solutions are divide in "based requirements", which are the minimum instrumentation we auspicate to have on the single machine and "desire requirements" for enhanced instrumentation and better performance. Quantitative consideration are not reported here for lackness of space.

Each machine is characterize by six degree of freedom, but two of them (depth and heading) are very easy to measure. If the machine has cylindrical symmetry one is uninfluenced. Considering the yaw not important (we image the navigation into one plane with the exception of few moments) we understand that the really difficult is to give coordinate x-y, of the center of mass; the x-y plane is that parallel to the bottom sea.

The base equipments of all the machine is composed by: Network communication, GPS, Depth meter, Inclinator, Compass, Flash, Photodiode, Webcamera, Livery on the vessel surface and/ electric or magnet device. All this equipment is cheap and available.

The network is a requirement that exist not only for the communications but must be used for data exchange and we are interest in its use like sonar ranging for RL. Of course the snapshot of situation suffered for a delay, presumably from tenths of a second to second and should be sent, together with the estimated robot speed for the correction. The network should be able to shift the working frequency from 100 to 1000 Khz (at least two frequencies). This number comes out from consideration on data rate and the use of the net as emergency ping or localization signal. The distance we want to cover (maximum 50 meter) and the data rate should be between 10 and 100 Kbytes/sec.

All the data available will be fuse and weighted with all the data coming from other instruments to be more precise in localization. More than an algorithm is desired, for example one more complex that use all the available data and one more quick using only a subset of data, depending on the operative conditions and on the kind of localization required.

GPS is used for AL when a scout (single robot that have this task) is on the surface.

At least a commercial depth meter must be present for AL in one dimensions.

A couple of inclinometer is useful to measure the angle of position with respect of the land. Another degree of freedom can be remove by compass; careful must be posed in case of the presence of magnetic disturbances.

A photodiode is useful to get flash lamp sequence for light communication; as example a codified sequence could send the heading of the machine to the other (close neighbors) to adapt themselves. Therefore to transmit simply codified message by flash we can transmit a sequence; working on color or flash time it is more complicate, standing the use of a cheaper flash unit. In some cases we can arrive to obtain an optical modem. This is a very cheaper and light instrument, but give not information on the position of the light source.

A webcamera must be used for image recording. Moreover together with an optical flash lamp. Using omnidirectional vision it is possible, with synchronized flash (or triggered by the first flash and using cumulative vision of few seconds) to get a qualitative information on the density of machine. Of course is not a metric information but the single machine can get the information if it is far or too left (for example) from the swarm. Moreover flash could be useful to rescue a single machine with difficult, together with a switch of the network toward lower frequency working to increase the range.

The camera can be used also in the livery lecture for IRL for fast reaction movement, but it needs a computational job that must be simplified; image analysis is too much heavy. This last work could be done as batch as for SLAM distributing the computational cost on a parallelized machined (the swarm itself if the network is adequate).

The single machine can be equipped with a strong electromagnet. The advantage of a static magnetic field is the possibilities to transmit (like flash sequence) some information to the other machines. Moreover the hope is, differently from the light source, to get some quantitative information on the RL by the magnetic field vector.

Electromagnetic transmission in sea water is going on some progress with respect of last years. A solution in the frequency window of low adsorption can be considered together with its power and dimensions cost. [10] [11].

Magnetic methods require some words more. An attempt to localize Rfid by magnetic field it has been performed in air [10]. We start to consider the Earth magnetic intensity field. Its scalar value is about 20 microTesla at the equator and 70 micro Tesla at the poles (1 Tesla=10000 Gauss). We can consider it constant in our area of operation with some exceptions. Moreover if we want to generate an added magnetic field we have to know how much is the sensitivity of the magnetometer and what field we are able to generate in a cheaper way. The temporal anomalies of the magnetic earth owing to the interaction of electric particle with magnetosphere are of 500 nanoTeslas maximum, with a life time between 1 and 1000 seconds. Anyway underwater they will be shielded. A commercial magnetometer has a scalar sensitivity of 0.01 nanoTeslas but it is quite large (A torpedo like about 1 meter long with 0.1 meter diameter [11]). A very cheaper (40 euros!) micro magnetometer has a sensitivity of 10 nanoTesla [12]. We can take in account that the nature of the sea bottom can give peak of about 10 nanoTEslas or more but in an area of more than 100 meter side; this system also is used to detect cultural heritage goods on the marine bottom . An easy coil is able to generate the magnetic static field [13, 14].

We can plot the field and do some consideration; if we consider, as example, a solenoid with 1000 turns, 0.1 meter radius, the center posed 1m on the z-axis and 1 Ampere current we can easy calculate the generated radial and axial magnetic field.

So far we should be able to detect the spike on the magnetic field (about 100 nanoTesla) superimposed to the Earth's field we have generated into the sea. We have now two opportunities; one is a slow modulation of the field (to reduce attenuation) carrying some codified information, like flash lamp. The second is to make an attempt to calculate the position of the field generator. this has been done for two object in open space and for wired system for augmented reality and the mentioned case of rfid localization. It is an hard chances to do for multisystem into the sea. more calculation to investigate this possibility need. From these we deduced that are able to detect the magnetic we hope to get some information (distance or heading direction or some other) form these numbers.

Some other equipment like Acoustic pinger, LBL USBL device, DVL, AHRS, Electromagnetic devices, Gradient localization can increase the performance of the system. An harbour could be equipped with no so high cost, with respect to the normal cost of surveillance. DVL can be mounted to integrate its data with cheaper AHRS (like XSense for example) for AL and RL (we avoid IMU for the cost). A quantitative measure of absorption of electromagnetic waves in the water led to the not possibility to use Radio frequency modem in sea water. Anyway using some particular window frequency and other system some device, with very poor performance, it has been build. In the last time electromagnetic device for marine application had an improvement in their performance lead to commercial products [14] it needs to investigate on this new device also if their dimensions seems to be too large for Harness project. Electric and static magnetic field also are under investigation.

The gradient localization is an example of no metric localization but only topological. The movement can be obtained like the force field used in obstacle avoidance techniques.

5.0 CONCLUSION

In this work we have explained as the Harness project could be useful for multipurpose use with particular attention to the harbour security problem. We propose a swarm of underwater cooperating robot.

The advantages lie in the economy of the method, the parallelization of the task and the robustness of the system. The disadvantage in the major control difficult of the swarm, owing to the presence of a new layer named as “Swarm control” which has different rules from the individual machine control. Many difficult are to be studied, especially in communication between the swarm elements owing to the unfriendly environment that limits the communication channel also if different methods are used.

Principal challenges are overcome the problem of low data transmission bandpass, improve the monitoring capability, get an easy and fast supervised control by a human operator introducing an high level decision capability in the control loop and optimize the system behavior in different environments to improve the robustness and the reliability of the system.

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